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SILVER BOW CREEK

REMEDIAL INVESTIGATION FINAL REPORT

APPENDIX A, PART 1

Report

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SURFACE-WATER AND

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Helena, Montana

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SILVER BOW CREEK REMEDIAL INVESTIGATION
DRAFT FINAL REPORT

SURFACE WATER AND POINT SOURCE INVESTIGATION
PART 1: REPORT

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January 1987

MultiTech

MAY 1 5 1991

PREFACE

Silver Bow Creek originates north of Butte, Montana and is a major tributary to the upper Clark Fork River. Mill tailings and other mining wastes in and near the creek contribute to substantial downstream contamination, particularly by potentially toxic elements: arsenic, cadmium, copper, lead, iron, and zinc. These elements and others were present in the mine ore and remain as by-products of the milling and smelting processes.

The history of mining in the Butte area began with the discovery of placer gold in Silver Bow Creek, in late summer of 1864. Several townsites and camps sprung up among the diggings. However, these operations were short-lived, and most of the miners left by 1869. Those who stayed began prospecting the quartz lode deposits of silver and the associated complex copper ores on the Butte Hill. Their efforts culminated in a silver rush, which began in the mid-1870's and revived the old camp. During that time world-class deposits of copper ore were identified. By 1881, Butte had become one of the nation's major mining centers; the district attained national dominance in copper mining by the mid-1890's and international prominence by the turn of the century. By 1915, Anaconda Copper Mining Company led the industry; but in 1980, in response to a depressed copper market, Anaconda closed all the underground mines and continued active mining only in the Berkeley Pit (established in 1955). In 1977, Anaconda became a subsidiary of Atlantic Richfield Company (ARCO). ARCO closed the Berkeley Pit in 1982 and the East Berkeley pit in 1983.

In addition to mining, various ore processing facilities also operated in the Butte area. The first two mills were erected in 1874 to smelt gold and silver. Ten years later, Marcus Daly, one of the founders of the Anaconda Company, built a copper smelter 27 miles west of Butte and planned the city of Anaconda. The Anaconda Smelter was moved to a new location in the city in 1900, and operated from 1903 to 1980.

The history of over 100 years of continuous mining and related activities changed the area's natural environment greatly. Early mining, milling, and smelting wastes were dumped directly into Silver Bow Creek and transported downstream to the Clark Fork River. In 1911, the first treatment pond was built by Anaconda Company near Warm Springs, Montana, to settle out wastes from Silver Bow Creek before the water was allowed to move on. In 1916 and 1959, two more treatment ponds began operation. Silver Bow Creek continued to receive raw mining and milling wastes until 1972, when a treatment plant was added to the Weed Concentrator in Butte. Creek contamination problems were compounded by urban and domestic sewage, wood products treatment plants, phosphate and manganese production facilities, and chemical factories.

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In 1983, the U.S. Environmental Protection Agency (USEPA) designated Silver Bow Creek, contiguous portions of the upper Clark Fork River, and their environs as a high priority Superfund clean-up site. The site extends from Butte to Deer Lodge, Montana, generally following the course of Silver Bow Creek and the upper Clark Fork River. Because the various mining activities interrupted the natural flow of Silver Bow Creek, the beginning of the creek for this investigation was established as the confluence of the Metro Storm Drain and Blacktail Creek, within the city limits of Butte. The site begins at the start of the Metro Storm Drain and ends at the Kohrs Bridge north of Deer Lodge.

The Silver Bow Creek Remedial Investigation (SBC RI) project consisted of coordinated individual studies to develop data on the extent and severity of contamination within the site. Results of the studies are reported in several volumes. A Summary Final Report discusses the entire project; final reports for each individual study have been issued as appendices to the Summary, as shown below:

- Surface Water and Point Source Investigation, Appendix A, Parts 1-3;
- Ground Water and Tailings Investigation, Appendix B, Parts 1-3;
- Warm Springs Ponds Investigation, Appendix C; 1d2
- Algae Investigation, Appendix D, Part 1;
- Vegetation Mapping, Appendix D, Part 2;
- Agriculture Investigation, Appendix D, Part 3;
- Macroinvertebrate Investigation, Appendix E, Part 1;
- Bioassay Investigation, Appendix E, Part 2;
- Fish Tissue Investigation, Appendix E, Part 3;
- Waterfowl Investigation, Appendix E, Part 4; and
- Laboratory Quality Assurance/Quality Control Program, Appendix F.

The Solid and Hazardous Waste Bureau (SHWB) of the Montana Department of Health and Environmental Sciences (MDHES) administered the USEPA appropriations to conduct this project. The Montana SHWB program manager was Mr. Michael Rubich. MDHES contracted with MultiTech in October 1984 to perform the SBC RI under contract No. 50341-1202503. The Project Manager at MultiTech was Mr. Gordon Huddleston.

MultiTech was assisted in the SBC RI work by Stiller and Associates of Helena and various other subcontractors. Several state and federal agencies also provided technical information and expertise, including the USEPA bioassay team, the Montana Department of Fish, Wildlife and Parks, the Montana Water Quality Bureau, and the USEPA Montana Field Office.

Information developed in the SBC RI will be used in the next phase of the project, the Feasibility Study, to evaluate options for site remediation.

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EXECUTIVE SUMMARY

The primary objective of the Surface Water and Point Source Investigation for the Silver Bow Creek (SBC) Remedial Investigation (RI) was to evaluate the extent and severity of contamination in the Silver Bow Creek/Upper Clark Fork River. Data collected from December 1984 to August 1985 provided the basis for evaluating the sources, transport, and fate of metals throughout the SBC RI study area. The investigation focused on six metals: arsenic, cadmium, copper, iron, lead, and zinc.

Definite evidence of severe and extensive surface water contamination was found in Silver Bow Creek and to a lesser extent in the upper Clark Fork River. The Butte Metro Storm Drain is the most severely contaminated part of the study area; cadmium and zinc concentrations regularly exceed Federal drinking water standards, and other contaminants (copper, arsenic, lead, and iron) are less frequently above drinking water standards. Missoula Gulch discharge to Silver Bow Creek regularly exceeds the drinking water standards for lead and less frequently for other metals.

The USEPA aquatic life criteria (1-hour) for copper and zinc are regularly exceeded throughout the SBC RI area. During a major storm event all measured total metals (arsenic, cadmium, copper, iron, lead, and zinc) exceeded Federal drinking water standards at most of the sampling points along Silver Bow Creek, demonstrating that both the severity and extent of contamination increases dramatically during runoff conditions. Measurable concentrations of pentachlorophenol were found below the Montana Pole and Treatment Plant Site; one sample exceeded the drinking water lifetime health advisory for adults.

Major sources of contamination were quantified both in terms of total metals load and relative contribution of each source to the water quality of the receiving stream. In general the contaminant sources in and near Butte were much more significant than sources further downstream. The most significant contaminant sources identified during the RI were:

- Ground-water inflow to Silver Bow Creek between Montana Street and the Colorado Tailings (GWI).
- Butte Metro Storm Drain (MSD) (primarily ground-water inflow).
- Butte Sewage Treatment Plant (STP).
- Browns Gulch (BG).
- Re-entrainment of sediments (SED), though not a true source.

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These sources were ranked according to the total quantity of each metal contributed to Silver Bow Creek during the entire RI period:

Arsenic: SED > GWI > BG > STP

Cadmium: GWI > MSD > STP >> other sources

Copper: GWI > SED >> STP > MSD

Iron: SED > BG > GWI >MSD

Lead: BG > SED >> other sources

Zinc: GWI > STP > MSD >> SED

Analysis of the RI data indicates that iron, copper, lead, and arsenic are transported in the solid phase, either as mineral sediments, precipitates, or adsorbates. Conditions throughout the SBC RI study area appear to favor precipitation of iron. However, since this process is slow (kinetically controlled), more dissolved iron is found then would be predicted by equilibrium calculations. Copper and arsenic adsorb to, and may be co-precipitated with, iron. Conditions favorable to copper precipitation exist downstream of the Colorado Tailings. Lead is generally not soluble and is transported primarily as mineral sediment. Conditions do not favor zinc precipitation anywhere in Silver Bow Creek, and both zinc and cadmium are transported primarily as dissolved constituents. Overall contaminant transport is most significant during the relatively few high flow events when solid phases are mobilized. Bedload sediment, although not measured during this RI, is probably significant in the transport of solid-phase contaminants in Silver Bow Creek.

Contaminants in Silver Bow Creek have two possible fates--entrapment in the Warm Springs Treatment Ponds or discharge to the Clark Fork River. When the relatively infrequent high flow events were integrated with the generally low-flow conditions experienced during this RI, the following conclusions were reached:

- The Warm Springs Ponds removed the following loads delivered by Silver Bow Creek during the RI period: approximately 90% of the cadmium, 70% of the zinc and lead, 60% of the copper, 50% of the iron, 35% of the arsenic, and 5% of the sulfate.

- The remaining loads were not removed and travelled into the upper Clark Fork River, where their ultimate fate is determined primarily by impoundments (dams) and natural processes in the river's environment.

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A significant overall finding is that, except for low flows during the summer, approximately 40% of the contaminants delivered to the Warm Springs Treatment Ponds are not removed and continue into the Clark Fork River.

Four recommendations are made for additional data collection deemed useful for feasibility studies of the Silver Bow Creek CERCLA site:

1) Identification of ultimate metals contaminant sources outside the current RI study area.

2) Evaluation of the effect of high flows and storm runoff on floodplain tailings deposits.

3) Monitoring of flow in Silver Bow Creek during a more normal (higher precipitation) year.

4) Additional characterization of the upper Clark Fork River.

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1.0 INTRODUCTION

The objective of the Silver Bow Creek Remedial Investigation (SBC RI) is to determine the extent and severity of contamination within the Silver Bow Creek/Upper Clark Fork River system (Map 1-1). Once the extent and severity of contamination within the site has been determined, the risk to humans can be assessed, and feasibility studies to develop remedial actions can be completed.

The SBC RI Surface Water and Point Source Investigation was designed and implemented to develop new data that could be used in conjunction with existing data, (1) to describe the extent and severity of surface water contamination in Silver Bow Creek and the upper Clark Fork River and (2) to assist in the evaluation, selection, and design of remedial alternatives. This report is the result of the investigation.

The Silver Bow Creek system has been contaminated by over 100 years of mining and smelting activities within the basin. A timeline showing significant historical events that impacted Silver Bow Creek and the upper Clark Fork River is shown in Figure 1-1. Although mining activities were suspended in this area during the RI, several possible sources still exist for continued water quality degradation of the system: tailings deposited in, and adjacent to, the surface waters; inflow of contaminated ground water; point-source discharges; and input from natural sources.

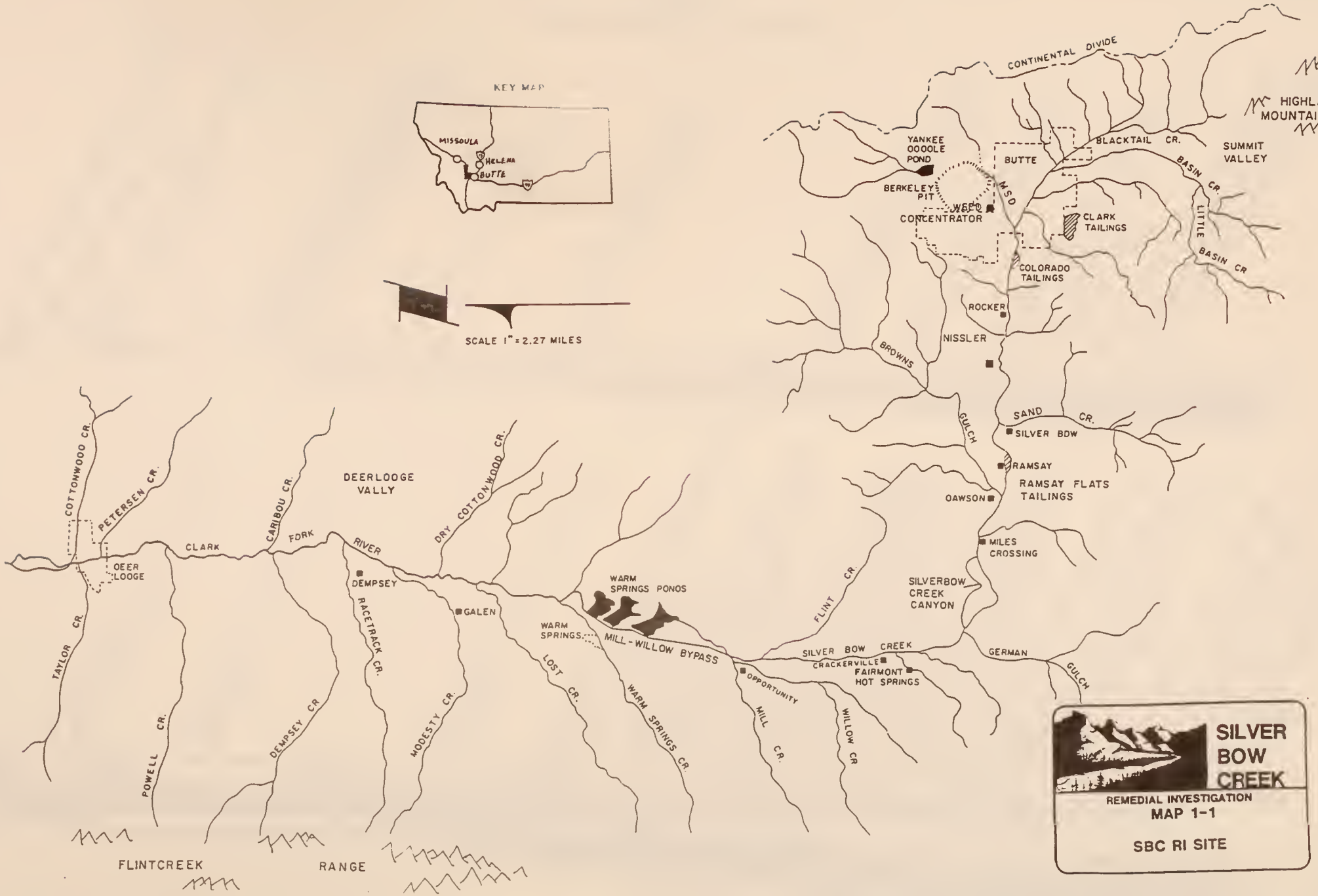
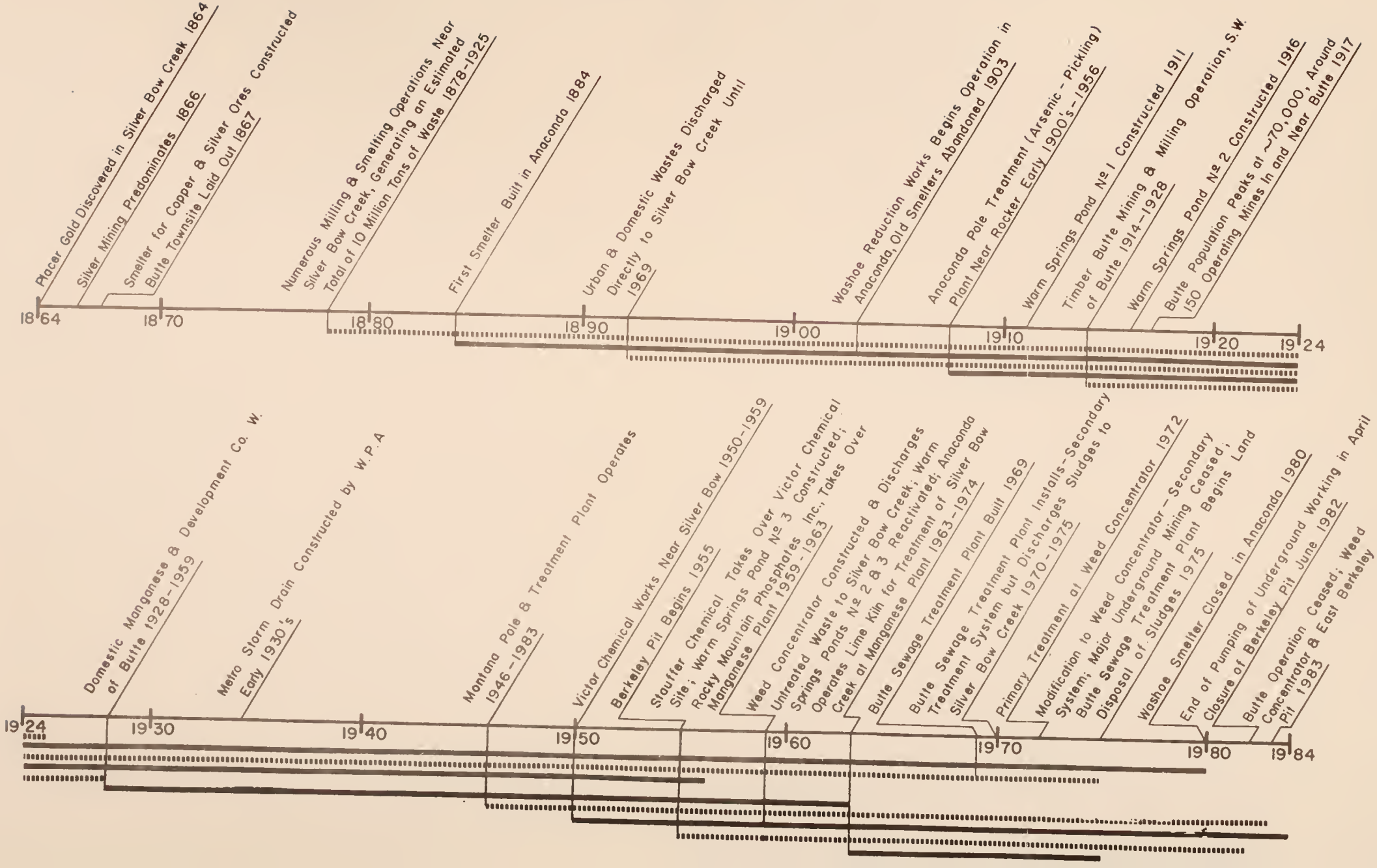

KEY MAP
MISSOULA
HELENA
BUTTE
SCALE 1" = 2.27 MILES
CONTINENTAL DIVIDE
HIGHLAND MOUNTAINS
YANKEE DOODLE POND
BERKELEY PIT
BUTTE
BLACKTAIL CR.
SUMMIT VALLEY
BASIN CR.
LITTLE BASIN CR.
M.S.D.
W.S.D. CONCENTRATOR
CLARK TAILINGS
COLORADO TAILINGS
ROCKER
NISSLER
BROWNS GULCH
SAND CR.
SILVER BOW
RAMSAY
RAMSAY FLATS TAILINGS
DAWSON
MILES CROSSING
SILVERBOW CREEK CANYON
FLINT CR.
GERMAN GULCH
SILVER BOW CREEK
CRACKERVILLE
FAIRMONT HOT SPRINGS
OPPORTUNITY
MILL CR.
WILLOW CR.
WARM SPRINGS PONDS
MILL-WILLOW BYPASS
WARM SPRINGS
WARM SPRINGS CR.
LOST CR.
GALEN
DEMPSEY
RACETRACK CR.
MODESTY CR.
DEERLODGE VALLY
DRY COTTONWOOD CR.
CARIBOU CR.
CLARK FORK RIVER
PETERSEN CR.
COTTONWOOD CR.
DEER LODGE
TAYLOR CR.
POWELL CR.
DEMPSEY CR.
FLINTCREEK RANGE
SILVER BOW CREEK
REMEDIAL INVESTIGATION
MAP 1-1
SBC RI SITE

FIGURE 1-1

HISTORIC CONTAMINATION OF SILVER BOW CREEK


Placer Gold Discovered in Silver Bow Creek 1864
Silver Mining Predominates 1866
Smelter for Copper & Silver Ores Constructed
Butte Townsite Laid Out 1867
Numerous Milling & Smelting Operations Near Silver Bow Creek, Generating an Estimated Total of 10 Million Tons of Waste 1878-1925
First Smelter Built in Anaconda 1884
Urban & Domestic Wastes Discharged Directly to Silver Bow Creek Until 1969
Washoe Reduction Works Begins Operation in Anaconda, Old Smelters Abandoned 1903
Anaconda Pole Treatment (Arsenic - Pickling) Plant Near Rocker Early 1900's - 1956
Warm Springs Pond Nº 1 Constructed 1911
Timber Butte Mining & Milling Operation, S.W. of Butte 1914-1928
Warm Springs Pond Nº 2 Constructed 1916
Butte Population Peaks at ~70,000; Around 150 Operating Mines In and Near Butte 1917
1864
1870
1880
1890
1900
1910
1920
1924
Domestic Manganese & Development Co. W. of Butte 1928-1959
Metro Storm Drain Constructed by W.P.A Early 1930's
Montana Pole & Treatment Plant Operates 1946-1983
Victor Chemical Works Near Silver Bow 1950-1959
Berkeley Pit Begins 1955
Stauffer Chemical Takes Over Victor Chemical Site; Warm Springs Pond Nº 3 Constructed; Rocky Mountain Phosphates Inc., Takes Over Manganese Plant 1959-1963
Weed Concentrator Constructed & Discharges Untreated Waste to Silver Bow Creek; Warm Springs Ponds Nº 2 & 3 Reactivated; Anaconda Operates Lime Kiln for Treatment of Silver Bow Creek at Manganese Plant 1963-1974
Butte Sewage Treatment Plant Built 1969
Butte Sewage Treatment Plant Installs-Secondary Treatment System but Discharges Sludges to Silver Bow Creek 1970-1975
Primary Treatment at Weed Concentrator 1972
Modification to Weed Concentrator - Secondary System; Major Underground Mining Ceased; Butte Sewage Treatment Plant Begins Land Disposal of Sludges 1975
Washoe Smelter Closed in Anaconda 1980
End of Pumping of Underground Working in April Closure of Berkeley Pit June 1982
Butte Operation Ceased; Weed Concentrator & East Berkeley Pit 1983
1924
1930
1940
1950
1960
1970
1980
1984

1.1 OBJECTIVES

Specific objectives of the Surface Water and Point Source Investigation were described in the SBC RI Work Plan (MultiTech and Stiller and Associates 1984):

- Determine the spatial and temporal variations in surface-water quality and quantity;
- Determine the most affected stream reaches and the sources or mechanisms within them causing water quality degradation;
- Determine how stream-water quality changes during major precipitation runoff events; and
- Determine how stream-water quality changes in response to ground-water discharges.

The spatial and temporal variations of surface-water quality and quantity indicate the sources, transport, and fate of metals in the creek. Water quality variations during major precipitation events are particularly important in identifying sources of metal contamination that reach the stream via a surface pathway. Another important contaminant pathway is ground-water inflow, and a major effort in this investigation was identifying possible ground-water inputs. The data collected help determine the relative importance of the two pathways, and thereby will aid in the selection of remedial alternatives.

Primarily, the following metals were studied: copper, zinc, iron, lead, arsenic, and cadmium. Other parameters were measured as factors affecting the chemical behavior of metals: temperature, pH, hardness, alkalinity, total suspended solids (TSS), and sulfate. Additionally, some samples were analyzed for polychlorinated biphenyls (PCB), or pentachlorophenol (PCP). This report describes methods of measuring those analytes and presents the results and interpretations of those measurements. In addition, previous studies were examined to extend the data base.

1.2 SITE DESCRIPTION

The SBC RI study area extends from near the Weed Concentrator in Butte to near Garrison in the Deer Lodge Valley (Map 1-1). It is within the Northern Rocky Mountain physiographic province.

The central focus of the investigation is Silver Bow Creek and its downstream extension, the upper Clark Fork River. Tributary streams were investigated only to assess their impact on these two stream courses. The system drains a total of 1,005 square miles, measured at Deer Lodge (U.S. Geological Survey 1983).

1.2.1 Surface Hydrology

Silver Bow Creek begins in Butte, at the confluence of the Metro Storm Drain (MSD) and Blacktail Creek, as shown in Map 1-2 (Over Size). The MSD is an open channel that was constructed in the

early 1930s under the Works Progress Administration Program by realigning and filling the original Silver Bow Creek drainage. Today, the MSD has little or no flow except during storm runoff or snowmelt episodes. Blacktail Creek originates in the Highland Mountains about 15 miles south of Butte and drains approximately 75 square miles.

Silver Bow Creek flows west about 10 miles, into a canyon beyond Miles Crossing (Map 1-3 Over Size). Within this canyon the creek swings northward and flows for another 10 miles (Map 1-4 Over Size), terminating in the Warm Springs Ponds system.

The Warm Springs Ponds area is discussed in a separate report, Appendix C. The ponds were built as an effort to treat the contaminated water flowing in Silver Bow Creek, and therefore they are a unique component of this system.

From the discharge of the Warm Springs Ponds, the stream course is called the upper Clark Fork River. The SBC RI follows the river to Garrison, where the study site ends (Map 1-5, Over Size).

The Butte Sewage Treatment Plant (STP) discharges into Silver Bow Creek on the western edge of the City of Butte (Map 1-2 Over Size). Minor ephemeral tributaries discharging into Silver Bow Creek in its upper reaches include Missoula Gulch, Whiskey Gulch, Gimlet Gulch, and Sand Creek. Perennial discharges to Silver Bow Creek

include Browns Gulch, Silver Lake Discharge (during the RI period), and German Gulch.

1.2.2 Climate

The study area has a continental climate with annual precipitation averaging 11.5 inches in Butte and 13.2 inches in Anaconda. Climate in the higher elevations surrounding the study area is alpine to subalpine, characterized by colder temperatures and heavier precipitation (often in the form of snow). Melting of the mountain snowpack in spring and early summer provides the majority of the surface water supply within the study area. Snow cover in the lower valleys usually melts in March to early April, with the mountain snowpack normally remaining through May and into June.

1.2.3 Geology

The geology underlying Silver Bow Creek ranges from Cretaceous intrusives and extrusives to Quaternary alluvium. The Boulder Batholith, in the eastern portion of the study area, is composed primarily of highly mineralized quartz monzonite. The Butte Mining District has been a major producer of gold, silver, and copper, and lesser quantities of cadmium, bismuth, arsenic, selenium, and tellurium (Miller 1973). The Deer Lodge Valley and the upper Clark Fork River are bounded on the west by the Anaconda-Pintlar and Flint Creek Ranges, which contain significant amounts of limestone. This

distinct lithologic difference is reflected in both soil character and surface- and ground-water chemistry.

1.2.4 Soils

A diversity of soil types are present in the study area. Soils in the basins are developed primarily on upland slopes under coniferous forests and on valley fill sediments under grassland vegetation. Adjacent to Silver Bow Creek and the Clark Fork River, shallow gravel-textured to deep fine-grained alluvial soils have developed. Nutrient-rich, organic soils of various depths are present in low or wetland areas.

Much of the natural soil in the study area has been affected by mining wastes such as mill tailings, smelter wastes, and stream-deposited tailings. Mining-related wastes are generally sandy textured, reflecting their granitic origin, and typically have high concentrations of metals and sulfide minerals. In addition, Silver Bow Creek flows through two major mining and milling waste deposits: the Colorado Tailings, located near Butte, and a large waste flat located near Ramsay. Significant waste deposits of varying thicknesses are present along the entire course of Silver Bow Creek and the upper Clark Fork River.

1.3 PREVIOUS INVESTIGATIONS

Although Silver Bow Creek and the upper Clark Fork River have a long history of water-quality problems, very little information was published before 1970. Several studies were performed during the 1970s, documenting the effectiveness of the Anaconda Mineral Company's (AMC) efforts to treat the water entering Silver Bow Creek from various operations. In February 1983, AMC's Weed Concentrator was closed. Studies prior to the closure do not accurately reflect current stream problems in the study area. The SBC RI supplies data that describe impacts of past mining, impacts that were only partially reduced by cessation of mining and milling.

1.3.1 Early Studies

The first published study of water quality in the Butte area was by Meinzer in 1914: The Water Resources of Butte, Montana. This study contained no surface-water quality data, although it described Silver Bow Creek as being "at times exceedingly dirty". Chemical analyses were performed in 1912 on wells in the Butte area, most of which had potable water, and on mine water, some of which had very high metals concentrations.

The next published study of water quality in the area did not appear until 1959, by Spindler: An Extensive, Chemical, Physical, Bacteriological, and Biological Survey, Columbia River Drainage, Montana. This report by the Montana State Board of Health included

studies of Silver Bow Creek and the upper Clark Fork River. It found Silver Bow Creek to be strictly an industrial waste conduit, almost devoid of life. However, it documented a recent improvement in water quality in the upper Clark Fork River which was attributed to the construction of the third Warm Springs Pond.

1.3.2 Studies From 1970 to 1983

The 1970s began a period of more frequent studies of Silver Bow Creek and the upper Clark Fork River. In 1970 the U.S. Environmental Protection Agency (USEPA) studied the upper Clark Fork River; however, it did not include Silver Bow Creek in the study (USEPA 1972). This was a water chemistry, benthic invertebrate, and fish study which showed a very poor biological community in the upper Clark Fork River. A similar conclusion was reached by Gless (1973) in a study of the upper Clark Fork drainage which included Silver Bow Creek. Gless found almost no invertebrates in Silver Bow Creek and attributed this lack to heavy metals loads and no suitable substrate. Diebold (1974) performed laboratory studies on the properties of Silver Bow Creek bottom sediments and concluded that the sediments had a great capacity for the adsorption of metals.

Primary and secondary treatment of waste water from the Weed Concentrator began in 1972 and 1975, respectively. AMC began efforts to clean up Silver Bow Creek because the Warm Springs Ponds were no longer providing sufficient protection for the Clark Fork River

(Spindler 1976). Self-monitoring data collected by AMC is available from this period, some of which is described in a Water Quality Inventory and Management Plan, Upper Clark Fork River Basin, tana (Casne et al. 1975). This document also describes a storm sewer study performed by the Montana Department of Health and Environmental Sciences' (MDHES) Water Quality Bureau (WQB) with cooperation from AMC.

By 1976 the water quality of Silver Bow Creek had improved greatly through the recycling and treatment of process waters at AMC's Butte Operations (Spindler 1976). This improvement in water quality is reported by Hydrometrics (1983) in a comprehensive study performed for AMC which also included additional storm runoff sampling, sampling of the water in the Colorado Tailings, and tailings material samples.

Other studies also reported on the water quality of Silver Bow Creek and the upper Clark Fork River in this period. Beuerman and Gleason (1978) sampled Silver Bow Creek during the summer of 1977. USEPA studied the surface water and tailings of Silver Bow Creek between Butte and Gregson in October 1978 (Peckham 1979). Sulfate data are also available from a study of the upper Clark Fork River in 1978 (Botz and Karp 1979). The above three studies were compared by James (1980).

AMC attempted to locate sources of metals loading to Silver Bow Creek in a study undertaken from May to June 1979 (Colvin 1979).

This study mainly addressed the contaminants contributed through the Harrison Avenue Storm Drain.

1.3.3 Post 1983 Studies

The MDHES WQB has collected data on Silver Bow Creek and the upper Clark Fork River since suspension of operations at the Weed Concentrator in February 1983. A stream-sampling program completed on April 27 and 28, 1983 was reported in An Intensive Survey of Silver Bow Creek and the Clark Fork River (Montana Department of Health and Environmental Sciences 1983). The WQB continues to collect data on the upper Clark Fork River and four stations on Silver Bow Creek as part of the Clark Fork River Survey.

Bank sediment data collected along the upper Clark Fork River is reported by Moore (1985) in Source of Metal Contamination in Milltown Reservoir, Montana: An Interpretation Based on Clark Fork River Bank Sediment.

The present RI fills several data gaps in the existing studies:

- Very few of the earlier studies collected samples from enough closely spaced stations on one date to allow identification of contaminant sources. Since the cessation of mining at the Butte Operations, only the WQB study of April 1983 provided any such data.

- Most of the studies, with the exception of the USEPA and the Montana WQB studies, did not analyze for dissolved metals. This omission makes identification of sources and understanding metals transport mechanisms difficult.
- Although some storm runoff data were available, the study by the Montana WQB in 1974 to 1975 did not contain representative sampling of the whole storm, and the studies by Hydrometrics and AMC did not sample truly intense events, judged by the flow data.
- If metals were determined in these studies, usually only copper and zinc were analyzed.

DRAFT

2.0 METHODS

Methods employed during the Surface Water and Point Source Investigation of the Silver Bow Creek Remedial Investigation (SBC RI) are the same as those described in the SBC RI Work Plan (MultiTech and Stiller and Associates 1984). This section describes existing data evaluation, field investigation methods, and data analysis and interpretation techniques. Where methods differed from those described in the Work Plan, appropriate justification is provided.

2.1 HISTORIC DATA COLLECTION AND EVALUATION

Historic surface-water and point-source data were collected from several sources, such as various state and federal regulatory agencies, published and unpublished reports, and the Anaconda Minerals Company (AMC). These data sources generally included water quality analyses, discharge measurements, and sampling locations.

Three review criteria were used to judge if historic surface-water and point-source data should be included in the computerized data base: (1) water quality data must have accompanying and concurrent discharge data; (2) the sampling party or agency must be identifiable; and (3) the sampling location must be identifiable. The compiled historic data then were evaluated in light of U.S. Environmental Protection Agency (USEPA) criteria for data acceptance.

The USEPA has two levels of Data Reliability Criteria, Level A and Level B, requiring different documentable information. Level A criteria includes the sampling date, location, and team; sample collection, preparation, and preservation techniques; shipping and analysis dates; laboratory preparation and analytical methods; and detection limits. Level B criteria includes all the criteria listed for Level A, plus quantitative statistical control samples, chain-of-custody control documents, and proper USEPA sampling and analysis protocol.

Data which meet Level A requirements only may be used to help direct the RI study. Data meeting Level B constraints can be included with RI-generated data for evaluating risks or remedial alternatives.

Only data collected during the period 1975 to 1985 were analyzed. In 1975, the quality of Butte Operations' discharge was notably improved by modifications to the Weed Concentrator. In February 1983, the Weed Concentrator was closed due to suspension of mining operations, and this discharge ceased. Therefore, data for the period 1975 to 1983 were analyzed separately from data collected from February 1983 to August 1985.

2.2 FIELD INVESTIGATION

The primary analytes of interest to the surface-water and point-source investigation are heavy metals (iron, zinc, copper, lead, cadmium, and arsenic). Parameter lists were developed initially

(Table 2-1) to quantify those parameters which historically were elevated in the surface and ground water, or those which could aid in identifying hydrochemical processes occurring within the study area.

Analytical parameters were adjusted during the course of the RI on a site-specific basis in response to data evaluation. These adjustments were made with the approval of the Montana Department of Health and Environmental Sciences (MDHES). Additional organic analyses were performed on selected samples: PCB, PCP, and oil and grease. Field data and samples were collected by Stiller and Associates, of Helena, Montana.

2.2.1 Location of Sampling Sites/Reconnaissance Survey

Surface-water and point-source sampling sites were located following a review of existing water quality and quantity data and after a field reconnaissance of point sources tributary to Silver Bow Creek. Sampling sites were located at all possibly significant point-source inputs and in reaches of the receiving stream above and below point-source inputs. Other sampling sites were located to provide adequate areal distribution.

Maps 1-2, 1-3, 1-4, and 1-5 (all Over Size) show the locations of the RI surface-water and point-source sampling stations. Figure 2-1

TABLE 2-1.--SURFACE-WATER AND POINT-SOURCE PARAMETER LISTS UTILIZED DURING THE SILVER BOW CREEK RI[a]

Category I	Category II	Category III	Category IV
Discharge	Discharge	Discharge	Discharge
Temperature	Temperature	Temperature	Temperature
Specific Conductivity	Specific Conductivity	Specific Conductivity	Specific Conductivity
pH	pH	pH	pH
	TDS [b] (measured)	TDS (measured)	Cu[f]
	TSS [c]	TSS	Fe[f]
	Sulfate	Sulfate	Zn[f]
	Nitrate (as N)	Nitrate (as N)	Alkalinity
	Alkalinity	Alkalinity	Hardness (as $CaCO_3$)
	Hardness (as $CaCO_3$)	Hardness (as $CaCO_3$)	
	Copper [d]	Copper [d]	
	Zinc [d]	Zinc [d]	
	Iron [d]	Iron [d]	
	Lead [e]	Lead [e]	
	Arsenic [e]	Arsenic [e]	
	Cadmium [e]	Cadmium [e]	
		Orthophosphate (as P)	
		Phosphorous (total)	

Notes:

(a) See Appendix F, Quality Assurance/Quality Control Summary, for analytical methods
(b) TDS - Total dissolved solids
(c) TSS - total suspended solids
(d) Total and dissolved constituents
(e) Total constitutents only
(f) Total and extractable constituents

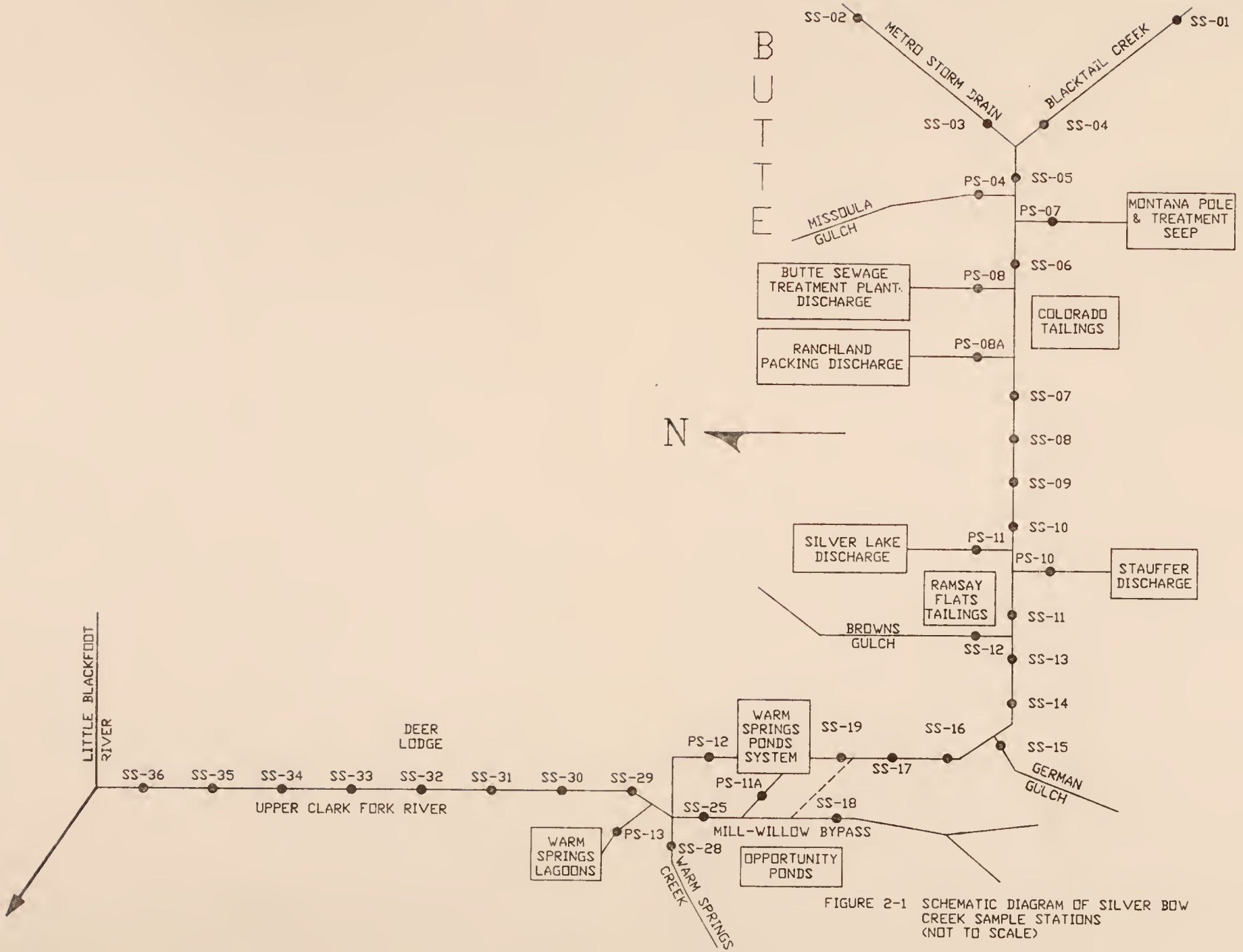


FIGURE 2-1 SCHEMATIC DIAGRAM OF SILVER BOW CREEK SAMPLE STATIONS (NOT TO SCALE)

schematically presents sample station locations and their relationships. Table 2-2 summarizes the sampling sites and associated analytical category, and a more detailed description of the sites is in Attachment I. Attempts were made to locate sampling stations in reaches of Silver Bow Creek and the upper Clark Fork River conducive to accurate discharge measurements and integrated sampling, yet with relatively easy access. Other considerations in siting the sampling stations include the following: (1) the proximity of U.S. Geological Survey (USGS) gaging stations; (2) locations of bridges for high-flow measurements; and (3) locations of suspected non-point sources of contamination.

Point-source inputs to Silver Bow Creek and the upper Clark Fork River were identified by field inspection, which involved walking the major water courses in the study area and inventorying all obvious and suspected point sources. The resultant inventory is presented in Attachment II. Information gathered during the reconnaissance point-source survey includes location, estimates or measurement of any discharges, and photographs. These data were used in the final determination of point-source and storm-runoff sampling locations.

2.2.2 Installation of Permanent Gaging Stations

Three permanent gaging stations were installed during November 1984, in accordance with the RI work plan, at sites SS-03, SS-14, and SS-17. A continuously recording gaging station was installed

TABLE 2-2.--SURFACE-WATER AND POINT-SOURCE STATION DESCRIPTIONS AND SAMPLE ANALYTICAL CATEGORIES

Site Number	Site Description	Sample Analytical Category[a]
SS-02	USGS gaging station at Texas Avenue (Metro Storm Drain)	II+O&G
SS-03	Kaw Avenue (Metro Storm Drain)	II+O&G
SS-01	USGS gaging station on Upper Blacktail Creek	I
SS-04	Blacktail Creek at Mouth	II
SS-05	Silver Bow Creek at Montana Street	II
PS-04	Missoula Gulch at Mouth	II
PS-07	Montana Pole and Treatment Seep (MP & T)	I+O&G+PCP
SS-06	Silver Bow Creek above Colorado Tailings	II+O&G+PCP
PS-08	Butte STP Discharge	II
PS-08A	Ranchland Packing Discharge	I+BOD
SS-07	Silver Bow Creek at USGS gaging station below Colorado Tailings	II+O&G+PCP
SS-08	Silver Bow Creek at Rocker	II
SS-09	Silver Bow Creek west of Nissler	II
SS-10	Silver Bow Creek near Silver Bow	III
PS-11	Silver Lake Pipeline Discharge	II
PS-10	Stauffer Chemical Discharge	I+F^-+PO_4+P
SS-11	Silver Bow Creek above Ramsay Flats	III
SS-12	Browns Gulch at Mouth	II
SS-13	Silver Bow Creek below Ramsay Flats	III
SS-14	Silver Bow Creek near Miles Crossing	III

TABLE 2-2.--SURFACE-WATER AND POINT-SOURCE STATION DESCRIPTIONS AND SAMPLE ANALYTICAL CATEGORIES (Continued)

Site Number	Site Description	Sample Analytical Category[a]
SS-15	German Gulch near mouth	II
SS-16	Silver Bow Creek at Gregson Bridge	II
SS-17	Silver Bow Creek at Stewart Street Bridge	II
SS-19	Silver Bow Creek at upper pH shack	III
SS-18	Mill-Willow Bypass at Frontage Road	II
PS-12	Pond 2 discharge	III
SS-25	Mill-Willow Bypass above Pond 2 discharge	II
SS-28	USGS gaging station on Warm Springs Creek at Warm Springs	II
PS-13	Warm Springs Lagoon discharge	II
SS-29	Clark Fork River at Perkins Lane Bridge	II
SS-30	Clark Fork River near Racetrack	IV
SS-31	Clark Fork River below Dempsey Creek confluence	IV
SS-32	USGS gaging station on Clark Fork at Deer Lodge	IV
SS-33	Clark Fork River at R.R. Crossing 3 miles north of Deer Lodge	IV
SS-34	Clark Fork River below Mullan Gulch confluence	IV
SS-35	Clark Fork River at R.R. Crossing 3 miles SE of Garrison Junction	IV

TABLE 2-2.--SURFACE-WATER AND POINT-SOURCE STATION DESCRIPTIONS AND SAMPLE ANALYTICAL CATEGORIES (Continued)

Site Number	Site Description	Sample Analytical Category[a]
SS-36	Clark Fork River above confluence with Little Blackfoot River	IV

Note:

(a) Categories are defined in Table 2-1. O&G - oil and grease, PCP - pentachlorophenol, F^- - Fluoride, PO_4 - orthophosphate, P - total phosphorus, BOD - biological oxygen demand.

during May 1985 at site SS-19 in conjunction with the mass-balance studies for the Warm Springs Treatment Ponds.

The continuous recorder at SS-03 was connected to a Parshall flume with a capacity of 100 cubic feet per second (cfs). The other recorders were connected to the natural stream channels. A typical installation is illustrated in Figure 2-2. Stage was determined using a float and pulley connected to an Omnidata electronic recorder which used an erasable, programmable, read-only memory chip (EPROM) for storage of data. Data were read using an Omnidata datapod reader and were stored on computer for analysis.

Staff gages were installed in the channel near the continuously recording gages. The staff gages were mounted on wooden beams supported by iron pipes driven into the stream bottom. The staff gages established a local datum to reference the recorder readings.

The continuously recording gages were monitored during regular sampling runs. During these visits the stilling wells were flushed, the staff gages were read, and the data recorders were checked for proper operation. Discharge measurements also were made with current meters to determine the stage-discharge relationship.

2.2.3 Sample Collection

Surface-water and point-source sampling began in December 1984 and terminated in August 1985; sampling dates are presented in

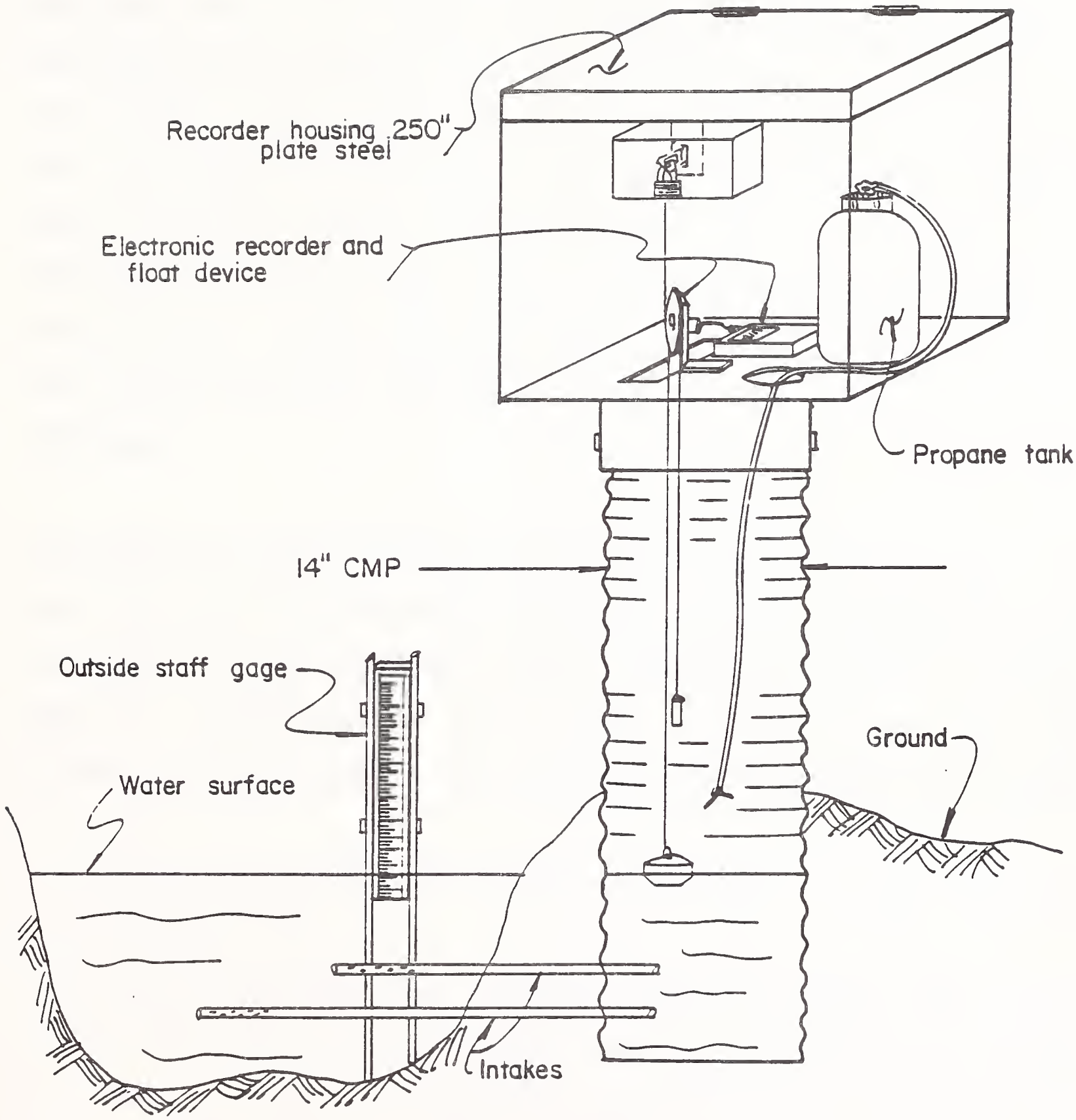


FIGURE 2-2

TYPICAL SURFACE-WATER GAGING STATION INSTALLATION

Table 2-3. Sampling was on a monthly schedule except for the period February through June 1985, when samples were taken twice monthly. Stations SS-30 through SS-36 on the Clark Fork River were sampled only twice, on May 22-23 and June 19-20, 1985 (Map 1-5 Over Size). The only change to the SBC RI Work Plan surface sampling schedule was at station SS-01, Upper Blacktail Creek at the USGS gaging station. The station was dropped from regular sampling in May 1985 because water quality analyses were not being performed for this site, and therefore, its impact on Silver Bow Creek could not be assessed.

Point-sources were sampled in conjunction with a storm event or as part of regular surface-water sampling, with the exception of PS-07 (Montana Pole and Treatment Seep), which was sampled quarterly. Table 2-2 summarizes the point-source sites and analytical categories. Changes made to the original work plan were as follows:

- PS-06, Manganese Plant Seep, did not appear during the course of this study.
- PS-10, Discharge near Stauffer Chemical Company, was changed to the regular surface-water sampling schedule in November 1984. The planned quarterly sampling schedule did not provide enough data to identify this site as a potential source of fluoride, orthophosphate, and total phosphorous in Silver Bow Creek.

TABLE 2-3.--SURFACE-WATER AND POINT-SOURCE SAMPLING DATES AND CORRESPONDING RUN NUMBERS

Sampling Date	Run Number
December 3-5, 1984	1
December 26-28, 1984	2
January 28-30, 1985	3
February 11-13, 1985	4
February 25-27, 1985	5
March 11-13, 1985	6
March 25-27, 1985	7
April 8-10, 1985	8
April 22-24, 1985	9
May 6-8, 1985	10
May 20-23, 1985	11
June 3-5, 1985	12
June 17-20, 1985	13
July 22-25, 1985	14
August 27-29, 1985	15

- PS-08A, Ranchland Packing Company discharge, was sampled with the surface-water stations. This station was dropped in May 1985 due to infrequent discharge and relative insignificance of total flow.
- PS-11A, Wildlife Ponds Discharge, was added as a monitoring site in November 1984, at the same frequency as surface-water monitoring sites. This site had been previously overlooked as a point-source discharge to the Mill-Willow Bypass.
- PS-13, Warm Springs Lagoon discharge, initially was added as a sampling site at the same frequency as surface-water stations, and subsequently was dropped from sample sites in May 1985. The site was sampled from December 1984 through May 1985 and was found to have insignificant impact, in terms of water quality and discharge, on the upper Clark Fork River.

Surface-water and point-source sites were sampled over a three- to four-day period by two or three sampling crews of two people each. Stations were sampled in upstream to downstream order, and crews tried to work concurrently in one reach of the stream so that time variations of parameter concentrations and streamflow would be kept to a minimum. The furthest downstream station measured on the previous day was regaged the following day to account for daily streamflow variations. This practice was initiated on the second sampling run in March and continued through the rest of the RI.

Gaging generally was performed with Price AA or pygmy current meters. Exceptions were SS-02 and PS-08, where weirs are present;

SS-03, where a flume was installed for the RI; and PS-08A and PS-13, where the bucket and stop watch method was most appropriate. Other measurements made in the field were water temperature, pH, and specific conductance. Details of field measurement procedures are found in Attachment III.

Field decontamination procedures were followed to avoid the contamination of samples, personnel, and equipment. Procedures were determined by the analyses to be performed and the risk of personnel and equipment contamination in a particular area. Attachment III details the decontamination procedures.

Water quality samples were collected from stream channels using DH-48 depth-integrated samplers. The total discharge of the stream was divided into four sections of equal discharge. Depth-integrated samples were taken at the midpoint of each section and combined in 1-gallon plastic sample containers. Pipe sources were usually sampled directly with the sample container. Water from the sample containers was poured into the appropriate bottle and preserved as required by the Quality Assurance/Quality Control (QA/QC) Plan (MultiTech and Stiller and Associates 1985). Dissolved constituents were filtered using 0.45 μ filters before being placed in sample bottles. Samples were tracked using taped bottle labels, laboratory analysis request forms, and chain-of-custody forms. QA/QC data are summarized in the SBC RI Report, Appendix F.

2.2.4 Seepage Runs

Seepage runs are measurements of discharge and associated water quality obtained during base-flow or near base-flow conditions at several reaches in a stream. By measuring streamflow in this manner, an analysis of the stream's influent and effluent characteristics can be completed and a better understanding of surface-water/ground-water interrelationships reached.

Because discharge measurements are completed during base-flow conditions, the influence of factors such as runoff and stream-stage fluctuations are minimized. Inherent to a seepage run is measurement of all tributary inputs to the stream under study so that compensation can be made for these influences.

Two seepage runs were conducted during the RI, both in 1985: July 22-25 and August 27-29. Maps 1-2, 1-3, and 1-4 (Over Size) show the locations of sampling sites used during the seepage run, and Attachment I lists river miles of the stations measured from Texas Avenue in Butte. Parameters measured during the seepage runs are listed in Table 2-4. Field parameter measurements, decontamination procedures, and sample custody protocol were completed in accordance with procedures outlined in Attachment III.

TABLE 2-4.--SEEPAGE RUN PARAMETER LIST

Discharge
Temperature
pH (field)
Specific Conductivity (field)
Sulfate
Chloride
Calcium
Magnesium
Sodium
Potassium
Alkalinity
Copper (a)
Zinc (a)

Note:

(a) Total, dissolved, and total extractable.

2.2.5 Storm Runoff Sampling

Storm runoff sampling was completed at selected sites in the Butte-Metro area during a significant storm runoff event on May 29, 1985. A second attempt was made to sample storm runoff on September 12, 1985, but failed due to the lack of significant precipitation and runoff.

During the initial storm runoff sampling event, persons were stationed at storm-drain outfalls and at other sites before the precipitation event began (see Map 2-1 and Table 2-5). During the rising limb of the storm hydrograph, water quality samples were collected and synchronous measurements of discharge were made every half hour or less. As the storm runoff peaked and receded, similar samples were collected and discharge measurements made at each site every hour until pre-storm conditions were reached.

Discharge measurement and sampling methods varied according to site conditions. Where appropriate, current meters and depth-integrated samplers were utilized. At some sites, indirect measurements of discharge and grab sampling were necessary. Table 2-6 summarizes discharge measurement and sampling methods employed for each site during the storm runoff sampling episode.

Subsequent to field activities, samples from each site were composited utilizing a cone splitter. This procedure involved calculating the volume of water from each sample necessary to represent the

TABLE 2-5.--SITES SAMPLED DURING THE STORM RUNOFF EVENT OF MAY 29, 1985

Site Number	Site Description	Sample Analytical Category
SS-02	USGS gaging station at Texas Avenue (Metro Storm Drain)	II
PS-0A	Walnut Street storm sewer outfall	II
PS-01	Warren Street storm sewer outfall	II
PS-02	Harrison Avenue storm sewer outfall	II
SS-03	Kaw Avenue (Metro Storm Drain)	II
SS-04	Blacktail Creek at mouth	II
PS-05	Kaw Avenue storm sewer outfall	II
PS-03	Montana Street storm sewer outfall	II
PS-04	Missoula Gulch at mouth	II
PS-08	Butte Sewage Treatment Plant discharge	II
SS-07	USGS gaging station below Colorado Tailings	II

TABLE 2-6.--STORM RUNOFF DISCHARGE AND SAMPLING METHODS

Station	Discharge Measurement Type	Sampling Method
SS-02	Wier	Grab
PS-0A	Pipeflow	Grab
PS-01	Pipeflow	Grab
PS-02	Pygmy	Grab
SS-03	Flume	DI[a]
SS-04	Price AA	DI[a]
PS-05	Pygmy	DI[a]
PS-03	Pipeflow	Grab
PS-04	Pygmy	DI[a]
PS-04	Wier	Grab
SS-07	USGS Gage	DI[a]

Note:

[a]DI = Depth Integrated

portion of the total storm runoff volume for which that sample was collected. Each sample collected was split in this manner; the result was a single composite sample from each sample site. The composited samples were preserved appropriately and transported to the laboratory for analysis. Sample custody protocol is described in Attachment III.

2.3 DATA ANALYSIS AND INTERPRETATION

The following section describes the methods of data analysis used in evaluating the RI data and historic data. The data base and its manipulation are briefly described; the methods specific to historic data analysis are recounted; and the methods most useful to analysis of current RI data are discussed. This section also reviews the metals transport mechanisms that may be important to Silver Bow Creek and the upper Clark Fork River.

2.3.1 Data Analysis

2.3.1.1 The Data Base and Its Manipulation

Data used in this analysis were entered into two main data bases, one for historic data and one for data collected in this RI. The data bases were established on a Data General MV4000 computer. The data base was manipulated and statistical analyses were performed using the SAS® software (SAS Institute, 1985).

Most analytical parameters were above their respective detection limits on Silver Bow Creek, although metals concentrations were often below the detection limit on the Clark Fork River. Because a very small number of concentrations were below detection, the bias introduced by setting those data equal to one-half the detection limit was small. Calculation of point source loadings were an exception to this rule, where below-detection data were set to zero to avoid a positive bias.

2.3.1.2 Data Validation

The QA/QC Plan prepared for the Silver Bow Creek RI (MultiTech and Stiller and Associates 1985) was closely followed. The QA/QC plan provides guidance in the following areas:

- Field procedures;
- Analytical laboratory protocol;
- Chain-of-custody procedures; and
- Data QA checks, including field measurement duplicates (flow, pH, SC, temperature); field blanks and duplicate samples; sample bank blanks, spikes, standards, and splits; laboratory blanks, spikes, calibration checks, and replicates; and referee laboratory duplicates.

Data generated during this RI were subjected to the rigorous Level B Data Reliability Criteria described previously in Section 2.1, and were considered validated if these criteria were met. The SBC

RI Laboratory Quality Assurance/Quality Control Program (Appendix F) contains a more detailed QA/QC discussion.

Some data were not validated for a variety of reasons, such as excessive holding time or laboratory data QA checks. These data are marked with asterisks in the data listing and were not used in data analysis, except regarding the use of unvalidated TSS values. Some analytical batches did not include a standard sample, because such a standard was not available at that time and was not required by the QA plan. The TSS data were flagged for this reason alone and are probably valid by all other criteria.

Data generated by field duplicate samples were used to estimate total measurement error. Sampling error was calculated using this total error and laboratory error included with each laboratory report.

The calculated measurement errors are minimized using the following procedure. In many cases, data from several sampling runs exhibited similar trends. When data from each of the runs were averaged, the resulting mean ($\bar{x}$) was a more reliable measure of the true value (μ) than each of the individual measures. This improvement in reliability is a direct consequence of the Central Limit Theorem:

$\bar{x}$ approaches μ as n is increased

Where:

$\bar{x}$ = the sample population mean

μ = the true population mean

n = the number of individual samples taken from the population.

However, this approach assumes all measures are made on a single population. This assumption can cause fundamental problems (i.e., comparing runoff conditions with base-flow conditions) and was used with caution (i.e., the data were segregated into hydrologic regimes, Section 3.2.1).

Propagation of error is also of concern. Consider, as an example, a load measurement which is a function of concentration and flow (load = flow x concentration x unit constant). An average flow measurement might have a relative standard deviation (RSD) of 10% (0.1), and a water quality analysis, an RSD of 5% (0.05). The total RSD for the load is not simply an additive process of (0.1) plus (0.05) = (0.15), or 15%. To calculate the most probable RSD for the load, the following equation should be used:

$$R_L = \sqrt{(R_A)^2 + (R_F)^2}$$

Where:

R_F = Relative standard deviation (RSD) of the flow measurement

R_A = RSD of the water quality analysis

R_L = Most probable RSD of the load calculation.

The result of this example calculation shows the most probable RSD for the load to be .112, or 11.2%.

2.3.1.3 Graphic Display

A number of computer programs were developed to graphically display the data on a plotter. For each standard surface-water run, graphs were developed of flow at all stations on Silver Bow Creek and loads of various parameters. Plots of concentrations of particular parameters at a single sampling station and over the sampling period also were developed. Additional graphs were developed to show the loads of various parameters at all stations on Silver Bow Creek during the seepage runs.

These graphs demonstrate the spatial and temporal distributions of contamination, indicate sources of contamination, and suggest possible metals transport mechanisms.

2.3.1.4 Historic Data Analysis

Historic data collection methods were described in Section 2.2. Average loads were calculated for parameters such as zinc, copper, and iron, which also were analyzed in the RI. Samples in the historic data base generally were analyzed for metals using the State of Montana total recoverable method, whereas the RI water-quality samples were analyzed for dissolved and total metals. This

difference makes comparison of metals data from the two data sets difficult.

Few samples within the historic data base were taken at more than one station on the same date, resulting in few loading graphs of the type developed for this RI. Historic storm runoff at storm drains PS-01 and PS-02 (Map 2-1) were not measured at flows nearly as high as those of the storm runoff sampling for this RI, making this comparison impractical.

2.3.1.5 RI Data Analysis

Current RI data were analyzed according to flow, parameter concentration, and parameter loadings. Flow was plotted for each run along Silver Bow Creek to show areas of streamflow increases. Known tributary inflows then were subtracted to identify reaches of possible ground-water inflow or stream loss. Irrigation withdrawals and returns were identified and were measured during the seepage runs. The only stretch of the study area that might be affected is between SS-16 and SS-19.

Concentration plots for several parameters were made showing the variation in concentration over the RI study period at a particular station. These plots identify trends in data, which in turn lead to an understanding of some of the processes operating in Silver Bow Creek.

An important use of the data was to calculate loads of various parameters, allowing identification of contaminant sources. Load is a measure of the amount of material that passes a given point on a stream in a given time. Load is calculated using the following equation, in the units of this report:

$$\text{Load (lbs/day)} = 5.3944 \times \text{Concentration (mg/L)} \times \text{Flow (cfs)}$$

The constant 5.3944 is a conversion factor that corrects for the change in units. Loads calculated using concentration data below the detection limit were reset to zero to avoid positive bias that could cause interpretation errors.

Analysis of load variation was done two ways. First, load was plotted against time at each sample station, allowing an analysis of temporal variations. Secondly, load was plotted against distance for each sampling run, demonstrating spatial effects over the entire study area. The two methods then were integrated to provide a basic understanding of possible contaminant sources and transport mechanisms along Silver Bow Creek.

Loading analysis is particularly useful in interpreting the storm runoff data. Upstream loads could be added and compared with the loads measured at two stations (SS-03 and SS-07) to help identify load sources and calculate the unmeasured component of the total load at these points.

Seepage run data were analyzed for inflows other than measured tributary inflows. Loading calculations of various parameters were used to identify non-point sources of increased load to Silver Bow Creek, such as ground-water inflow and bank entrainment.

Most of the data analysis centers around copper, iron, and zinc. These metals are not necessarily the most toxic to humans at the site, but they are selected for several reasons:

- Zinc and copper are of particular concern for aquatic life at the levels measured in Silver Bow Creek. Iron is important as an indicator of chemical conditions and often affects the behavior of other metals.
- These metals have the highest concentrations of all heavy metals in Silver Bow Creek and are generally above detection limits along the entire study area. They are also reliable, routine analyses.
- The historic data contain very few metal analyses other than zinc and copper. Analysis for these metals provide some comparability with historic data.

2.3.2 Hydrogeochemical Hypotheses

The occurrence, transport, and fate of metal contaminants in Silver Bow Creek are controlled by several interrelated hydrogeochemical mechanisms. Though each mechanism is a distinct chemical phenomenon, the data collected during this study are insufficient to

conduct a detailed investigation into the variety of possible chemical processes acting in this system. However, three potentially important mechanisms can be semi-quantified from the existing RI data and used to evaluate metals behavior in Silver Bow Creek:

- Dissolution and precipitation of metal compounds;
- Adsorption and desorption of metal ions; and
- Physical transport of metalliferous sediments.

The possible role of algae in the accumulation and transport of metals is discussed in the Algae Investigation Report, Appendix D, Part 1.

The chemical forms of a particular metal in the stream can be very important for assessing potential toxicity. The Bioassay Investigation (Appendix E, Part 2) evaluates the actual toxicity of metals on young fish populations in the upper Clark Fork River. The various metal species present in Silver Bow Creek theoretically can be calculated from measured concentrations, but this usually represents an approximation and can be misleading. Figure 2-3 summarizes the more common forms of metals found in natural waters and some of their interactions with one another.

2.3.2.1 Dissolution and Precipitation of Metal Compounds

Predicting the dissolution and precipitation of various metal compounds rests on the basic assumption that thermodynamic equilibrium

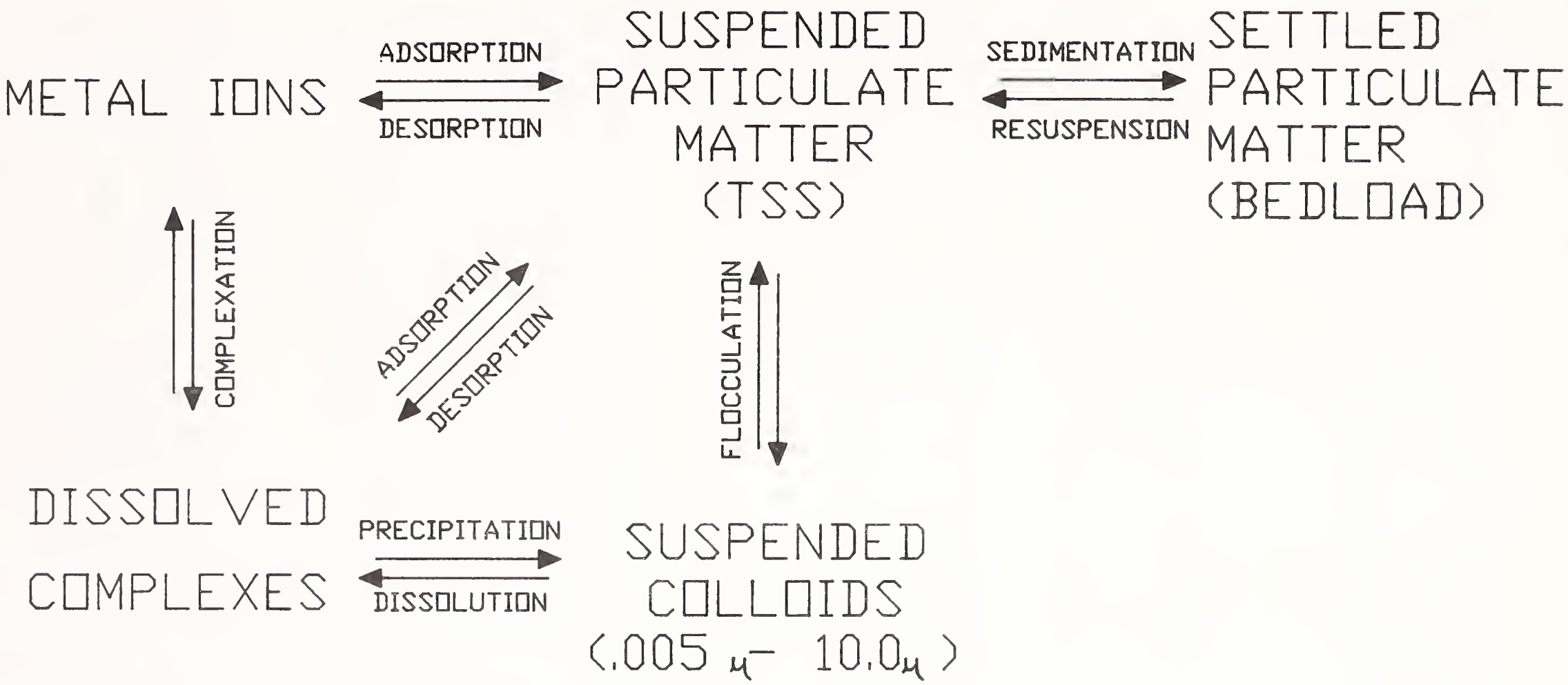


FIGURE 2-3 COMMON FORMS OF METALS
IN NATURAL WATERS
(after Salomons & Forstner, 1984)
p.14

is approached or attained by the system being studied. Several factors control calculated thermodynamic stabilities, including pH, oxidation potential, temperature, ligand concentrations, and activity coefficients.

Hydrogen ion concentrations (measured as pH) are an important factor in stability relationships. During the study period, pH varied from 6.0 to 9.2, a considerable range for equilibrium calculations.

Oxidation potential data, measured as Eh in volts, was not collected in this study. However, Eh for well mixed surface streams like Silver Bow Creek is usually moderately oxidizing, ranging from 0.35 to 0.55 volts (Hem 1970). This range is not generally sufficient to cause changes in stabilities of most of the compounds of interest.

Temperature was measured during the study and ranged from 0 to 25 degrees centigrade, though the range during any given sampling episode was only a few degrees. The small temperature differences and the relatively small effect of temperature on mineral stabilities make the effects of temperature relatively insignificant for equilibrium calculations.

The concentration of various ligands in solution with metals is very important to the calculation of relative stabilities. Ligands such as carbonate, sulfate, and hydroxide were all measured, while

organic complexing ligands were not. These measurements are important in determining the affinity of the various complexing agents to form stable complexes and precipitates.

Activity coefficients are important in relating measured concentrations of a constituent to those effectively available for chemical reaction (activity). The activity of a particular species is very dependent on the ionic strength of the solution, which indicates the effect of competing species also available for reaction. Ionic strengths in Silver Bow Creek were calculated using data generated during the seepage runs, which included measurements of major cations and anions in addition to the routine analyses. These calculations indicate that the activities for many of the species of interest are significantly reduced by the high concentrations of dissolved solids in the creek. Solubility diagrams have been prepared for copper, zinc, and iron (Figures 2-4, 2-5, and 2-6, respectively) using averages of the important parameters discussed above that were measured in Silver Bow Creek during the RI.

A variety of problems can arise from assuming equilibrium. Thermodynamics serves to predict the direction and extent of chemical change in a system. The rate at which these changes occur (kinetics) is very important to the observed chemical composition. Reaction kinetics for most of the species of interest in this study have not been well documented. Both the iron and manganese systems have been studied, however, and rate equations have been derived for

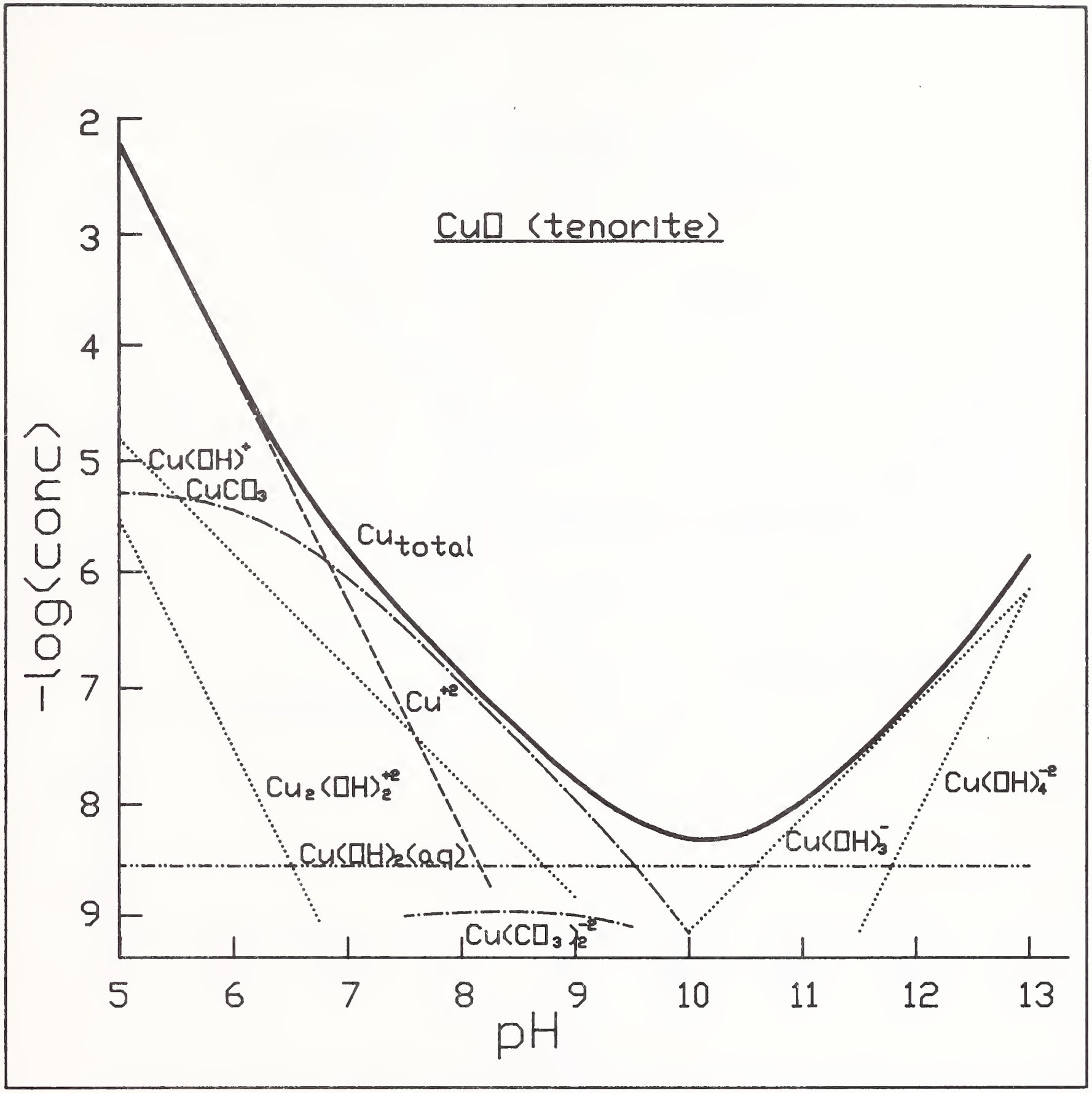


FIGURE 2-4
SOLUBILITY OF COPPER

Equilibrium constants were adjusted to ionic strength of 0.005, and calculations assumed total carbonate (carbonic acid, bicarbonate, and carbonate) was fixed at 100 ppm as $CaCO_3$, conditions representative of Silver Bow Creek. Data was not available to correct equilibrium constants from 25°C to conditions representative of Silver Bow Creek. The maximum error due to temperature variation from 25°C was estimated to be 0.2 log units in total copper concentration. Species considered were CuO (tenorite), $Cu_2(OH)_2CO_3$ (malachite), $Cu_3(OH)_2(CO_3)_2$ (azurite), $CuCO_3(aq)$, Cu^{2+}, $CuOH^+$, $Cu(OH)_2$ (aq), $Cu(OH_3)^-$, $Cu(OH)_4^{2-}$, $H_2CO_3^-$, CO_3^{2-}, $Cu_2(OH)_2^{2+}$, OH^-, and H^+. Equilibrium constants are from Stumm and Morgan (1981), except the formation constants for $CuOH^+$ and $Cu(OH)_2$ (aq) are from Morel (1983).

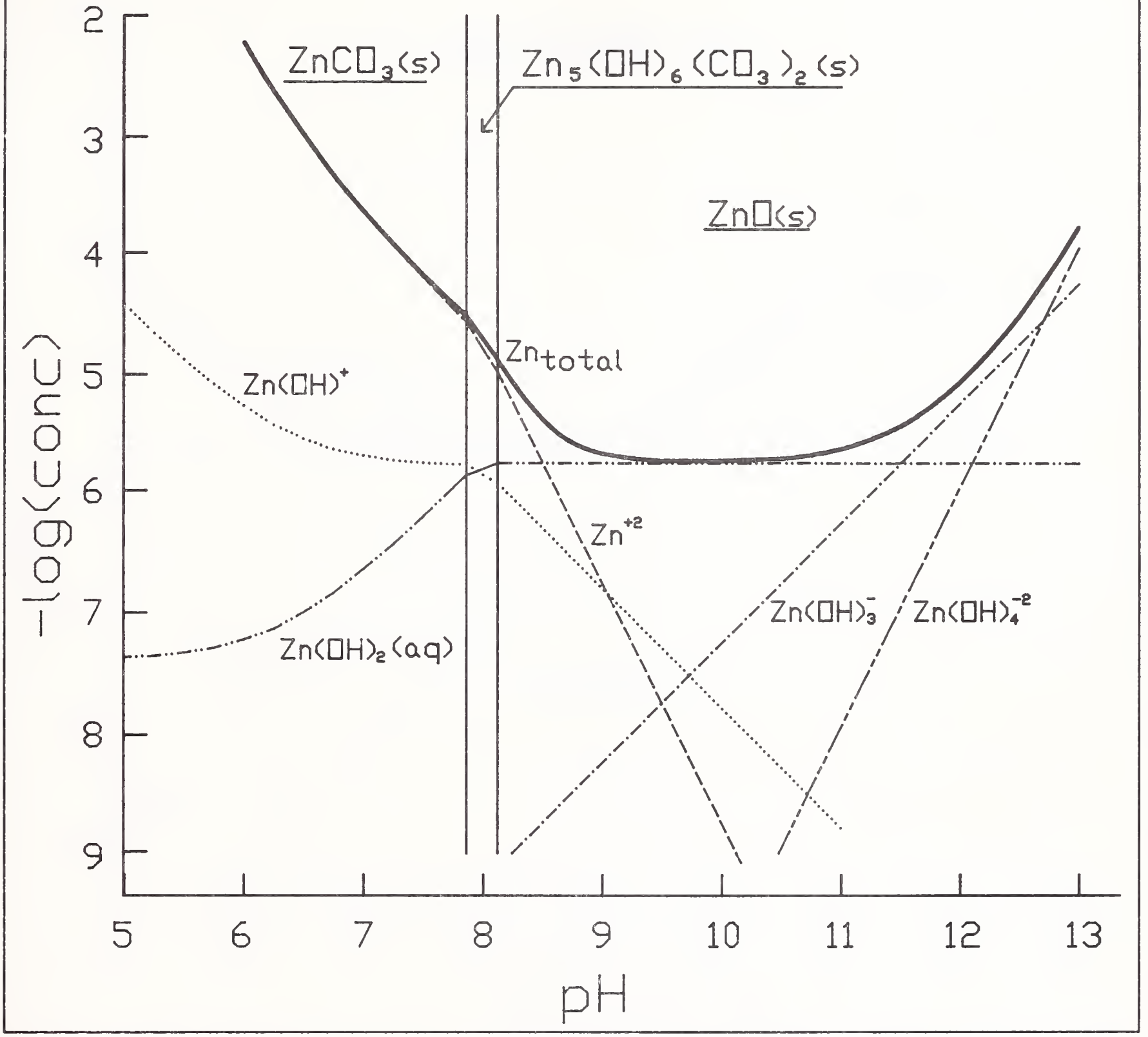


FIGURE 2-5
SOLUBILITY OF ZINC

Equilibrium constants were adjusted to ionic strength of 0.005, and calculations assumed total carbonate (carbonic acid, bicarbonate, and carbonate) was fixed at 100 ppm as $CaCO_3$, conditions representative of Silver Bow Creek. Data was not available to correct equilibrium constants from 25°C to conditions representative of Silver Bow Creek. The maximum error due to temperature variation from 25°C was estimated to be 0.2 log units in total zinc concentration. Species considered were ZnO(s), $Zn(OH)_2$ (amorphous), Zn^{2+}, $ZnOH^+$, $Zn(OH)_2$ (aq), $Zn(OH)_3^-$, $Zn(OH)_4^{2-}$, $ZnCO_3(s)$, $Zn_5(OH)_6(CO_3)_2$ (hydrozincite), $H_2CO_3(aq)$, HCO_3^-, CO_3^{2-}, OH^{-2}, and H^+. Equilibrium constants were taken from Stumm and Morgan (1981).

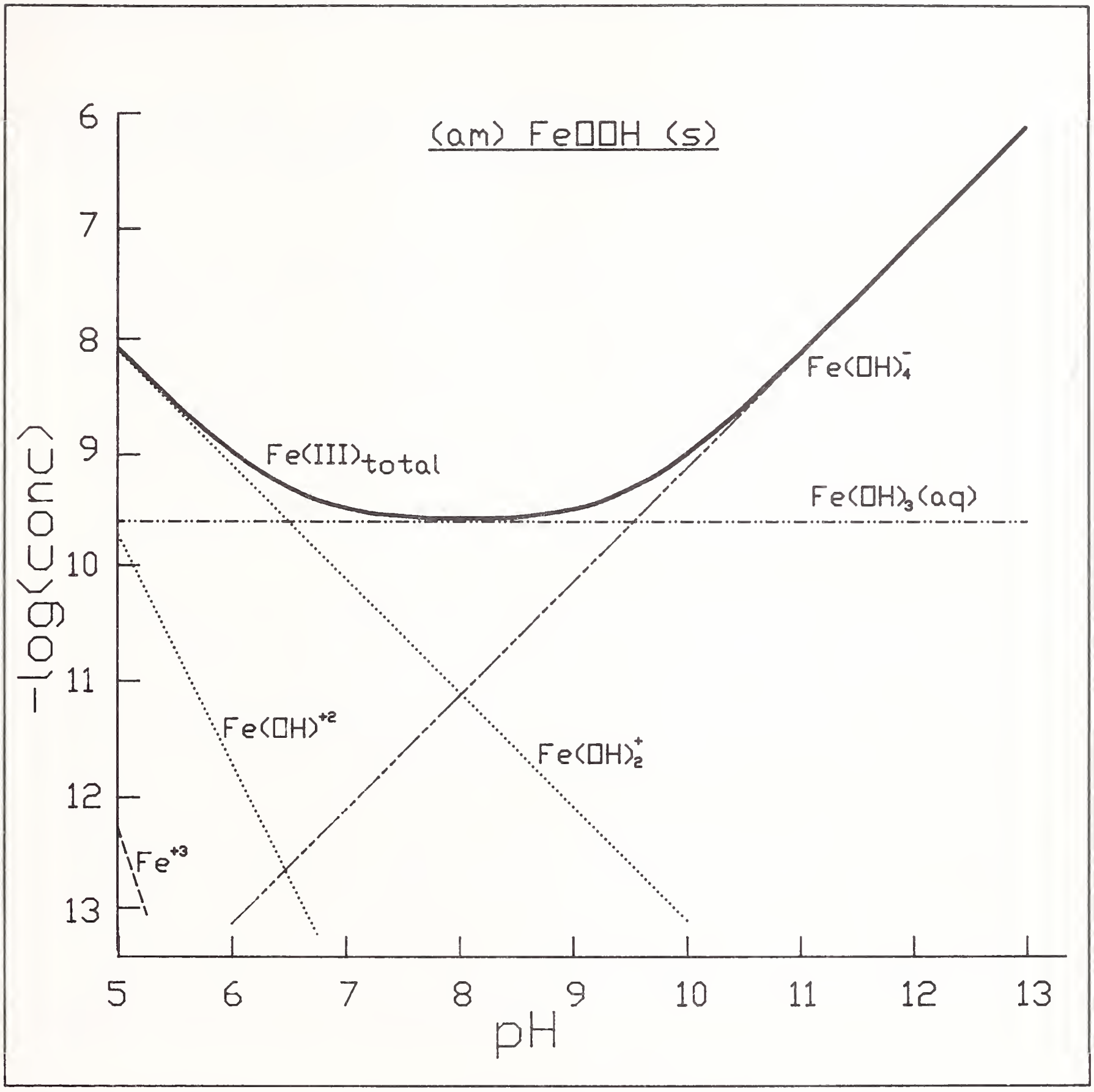


FIGURE 2-6
SOLUBILITY OF Fe (III) SPECIES

Equilibrium constants were adjusted to ionic strength of 0.005, and calculations assumed total carbonate (carbonic acid, bicarbonate, and carbonate) was fixed at 100 ppm as $CaCO_3$, conditions representative of Silver Bow Creek. Data was not available to correct equilibrium constants from 25°C to conditions representative of Silver Bow Creek. The maximum error due to temperature variation from 25°C was estimated to be 0.2 log units in total Fe (III) concentration. Species considered were FeOOH(amorphous), $FeOH^{2+}$, $FeOH_2^{+}$, $Fe(OH)_3$ (aq), $Fe(OH)_4^{-}$, $Fe_2(OH)_2^{4+}$, H_2CO_3, HCO_3^{-}, CO_3^{2-}, OH^{-}, and H^{+}. Equilibrium constants were taken from Stumm and Morgan (1981).

several reactions (Stumm and Morgan 1981). The following is an example of the effects of reaction kinetics:

> Using the thermodynamic equilibrium model for the iron system (Figure 2-6), a pH change from 6.0 to 7.0 should cause dissolved Fe^{2+} to form the precipitate $Fe(OH)_3$. However, before that can happen, Fe^{2+} must be oxidized to Fe^{3+}, which is a relatively slow process that is also pH- dependent (at pH=4, 10 years to completion; at pH = 7.5, 1.1 hours to completion).

The example may explain why frequently more dissolved iron is found in Silver Bow Creek than predicted by thermodynamic equilibria. Reaction kinetics, rather than thermodynamics, may dictate which metal species predominate in the waters of Silver Bow Creek. Supersaturation of the water with respect to a given constituent can occur easily and would yield dissolved concentrations higher than that calculated thermodynamically. Possible constraints due to reaction kinetics must be carefully considered when using thermodynamic solubility information.

A variety of organic substances can form complexes with metals that will alter the dissolved metal concentrations from those expected. Without a direct measurement of these organic complexes, their effect on dissolution and precipitation of metals is difficult to interpret. These organic compounds have a significant influence on metals in most surface-water systems.

Algae may indirectly influence metals behavior in Silver Bow Creek. During periods of photosynthetic activity, algae assimilate carbon dioxide out of solution, thereby increasing the pH. This activity may change the pH enough to cause the precipitation of some metals out of solution (Fogg 1965). Other aquatic organisms can affect the chemical speciation of certain metals and thereby complicate the interpretation of data.

2.3.2.2 Adsorption and Desorption of Metal Ions

Adsorption is a major process governing the transport and fate of metals in Silver Bow Creek, perhaps more important than precipitation. There are three categories of adsorption phenomena:

- Physical adsorption of solutes on the external surfaces of particles due to the relatively weak Van der Waals forces between them;
- Chemical associations between ions in solution and those on the surface of particles; and
- Ion exchanges involving positive or negative surface charges, attracting oppositely charged ions from the solution.

The surfaces required for adsorption can be provided by precipitated iron and manganese oxides and hydroxides, organic matter, and silt or clay particles. After initial adsorption on a surface (especially iron hydroxides), metal ions may become overgrown by the precipitating phase and be removed from the system. This process is also known

as coprecipitation or occlusion. Several factors can control the amount of metals affected by adsorption, including the following:

- The activity of the metal in the solution (calculated from the ionic strength);
- The pH of the solution--generally higher pH leads to increased metal adsorption (Figure 2-7);
- The number or density of adsorption sites (or total surface area available), which can be roughly correlated with TSS concentration;
- The activity of competing adsorbate ions in the solution;
- The concentration of ligands available to complex or precipitate metals and the thermodynamic stability and reaction kinetics of those species; and
- The kinetics of adsorption processes, which can have equilibration times of minutes to hours (Morel 1983).

Interactions between particles and metal species play an important role in the regulation of dissolved metal concentrations. Adsorption can be the first step in the ultimate removal of trace metals from the aquatic environment. Unfortunately, not enough is known about specific adsorption/desorption phenomena to provide more than a qualitative estimate of those effects on the Silver Bow Creek system.

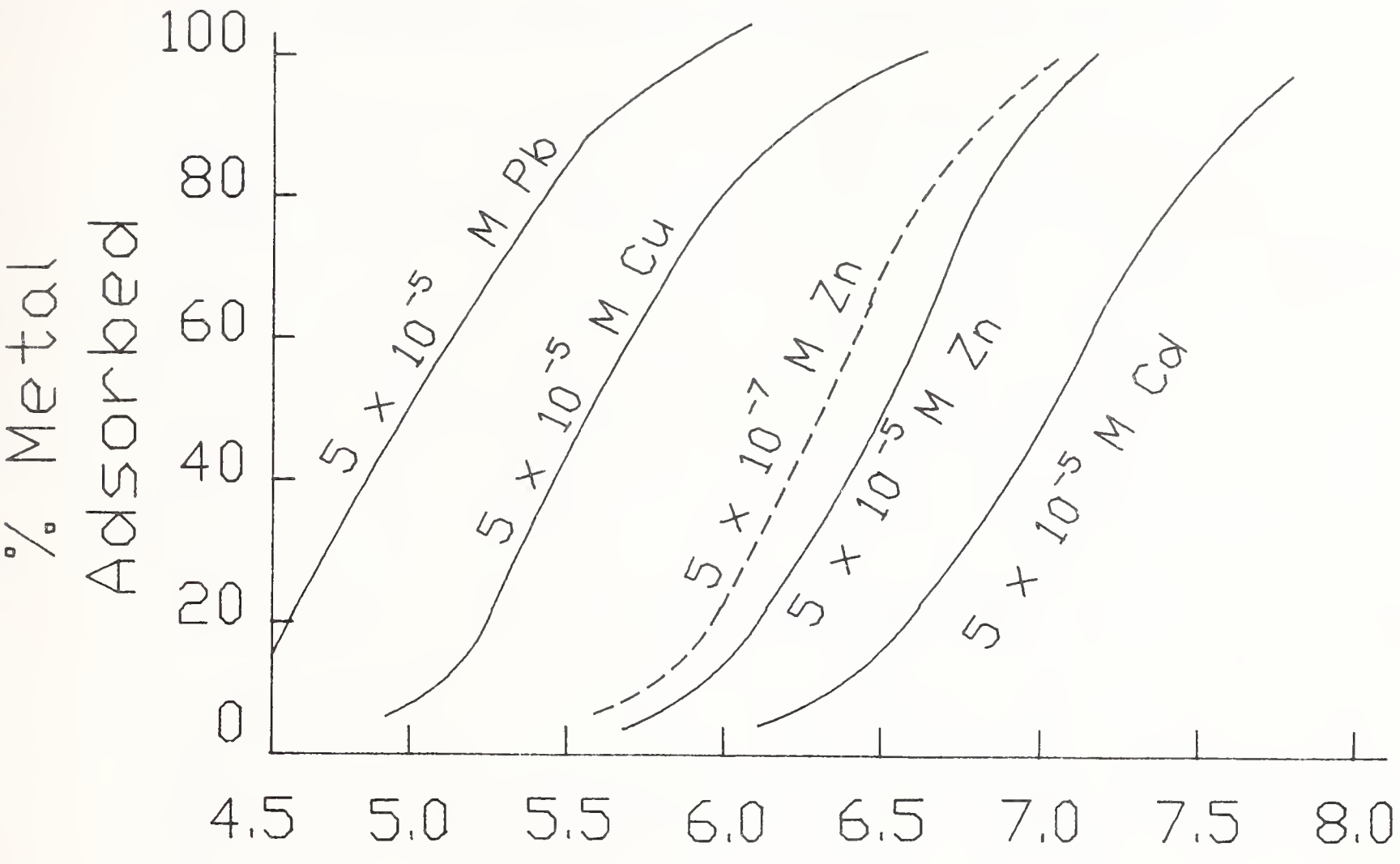


FIGURE 2-7

Fractional adsorption of metals on amorphous $Fe(OH)_3$ substrate (1×10^{3}M $Fe(OH)_3$) demonstrating the effects of pH, metal concentration (Zn), and different metals on adsorption tendencies (Salomons and Forstner 1984).

2.3.2.3 Physical Transport of Metalliferous Sediments

This mechanism includes the transport and fate of metal-rich particles occurring as suspended material (TSS) and as bedload sediment (not measured). This mechanism is difficult to quantify completely, as only metals in the suspended phase were measured during the RI. Transport and settling of particles is dependent on stream velocity, which can vary considerably with the width, shape, and total flow of a particular stretch of stream. This mechanism is more important closer to the streambed, where smaller particles can settle or be resuspended, and larger particles can bounce, roll, or remain stationary until an extremely high flow event. During flood events, metal-laden sediment may be carried over banks and deposited in the floodplain. Leaching of these deposits may occur, returning metals to the stream through surface runoff or ground-water discharge.

The high flow event sampled on June 3, 1985 can be used to study the extent of bedload sediment and stream bank entrainment into Silver Bow Creek. This high flow appears to originate upstream of Butte, so the effects of Butte's surface runoff are minimized while the sediment entrainment phenomena of a high-flow event are emphasized.

2.3.3 Analytical Constraints

Water samples collected during the Silver Bow Creek RI were routinely analyzed for metals in two ways (see Appendix F, QA/QC Summary, for

analytical methods). One split of the sample was filtered through a 0.45 micron (μ) filter before analysis to segregate "dissolved" metal species: free metal ions, inorganic ion pairs, and soluble inorganic and organic complexes. Another unfiltered split was analyzed for "total" metals. This measure included all the dissolved metal species listed above, plus those metals associated with suspended particulates: metals adsorbed on particle surfaces, precipitated metal compounds, and metals bound within the mineral matrix.

Adsorbed metals concentrations were determined using an "extractable metals" procedure, but this was done on only two sampling episodes. Subtracting "dissolved" metals from "extractable" metals yields a good approximation of metals present as adsorbed species. Subtracting both the "dissolved" and "extractable" metals from the "total" metals yields the metal that is bound within the mineral matrix of the sediment. Although a filter was used to separate dissolved metals from suspended metals, some colloidal particles (0.005μ to 10.0μ diameter) could pass through the 0.45μ filter. Some metals tend to form colloidal oxide or hydroxide precipitates; for example, iron forms ferric hydroxide ($Fe(OH)_3$) (Figure 2-6). Metal concentrations measured in the filtered split may actually include some colloidal material, and this material could cause equilibrium calculations to be inaccurate. The extent of this problem is unknown. Though it has limitations, filtration is still the best available technique for separating dissolved constituents.

These analytical extraction techniques limit predictions of theoretical chemical speciations and interactions. However, useful insight into the major chemical and physical processes as they apply to contaminant sources, transport mechanisms, and fate can be derived from these measurements.

DRAFT

3.0 DATA ANALYSIS AND INTERPRETATION

Both historic and remedial investigation (RI) data were reviewed and analyzed for this report. Emphasis was placed on the RI data, and historic data were used for comparison only. Included in this chapter are sections describing the historic data, the RI hydrologic data, and the sources, transport, and fate of contaminants found in Silver Bow Creek during the RI. The storm runoff data collected at the end of May and the seepage run data collected in July and August are integrated into the discussions of sources and transport.

The Warm Springs Ponds area is not covered in this report, but is discussed in detail in the Warm Springs Ponds Investigation Report, Appendix C. The limited data collected downstream from the ponds in the Upper Clark Fork River are included in the discussion of contaminant fate.

3.1 HISTORIC DATA

Published historic data were found in the following studies: Spindler (1959), U.S. Environmental Protection Agency (1972), Gless (1973), Diebold (1974), Casne et al. (1975), Spindler (1976), Beuerman and Gleason (1978), Botz and Karp (1979), Colvin (1979), Peckham (1979), James (1980), Hydrometrics (1983), and Montana Department of Health and Environmental Sciences (1983). Unpublished

data were found in Anaconda Minerals Company records and Montana Water Quality Bureau records.

3.1.1 Major Parameters

Table 3-1 presents averaged published and unpublished historic data from available sources for flow, specific conductivity, pH, sulfate, arsenic, cadmium, copper, iron, manganese, lead, and zinc for stations corresponding to those sampled during this RI. These parameters are discussed by broad geographic stream reach in the following sections. Historic data for portions of Silver Bow Creek do not include analyses for specific conductance, pH, arsenic, cadmium, copper, manganese, lead, or sulfate.

3.1.1.1 Upper Silver Bow Creek

Prior to the closure of the Weed Concentrator in 1983, water quality in Silver Bow Creek was affected by a fairly constant, permitted discharge of about 10 cfs from the Weed Concentrator, part of Anaconda's Butte Operations. This discharge entered the Metro Storm Drain (MSD) at Texas Avenue, just upstream of station SS-02 (Map 1-2 Over Size), and was normally the only contribution to the MSD at this point. The discharge of 10 cfs before the concentrator closure compares to measurable flows (five of fifteen sampling episodes) ranging from 0.002 to 0.10 cfs during the RI.

TABLE 3-1

MEAN VALUES OF PUBLISHED AND UNPUBLISHED HISTORIC DATA
(1975 - 1985) COMPARED TO FEDERAL DRINKING WATER STANDARDS[a,b]

Station	Discharge cfs		Sp. Conductance µmhos/cm		pH (s.u.)		Sulfate (mg/L)		Arsenic (mg/L)	
	$\bar{x}$	N	$\bar{x}$	N	$\bar{x}$	N	$\bar{x}$	N	$\bar{x}$	N
Federal Standard[c]	--	--	--	--	6.5-8.5	--	250	--	0.05	—
SS-02	9.6	90	1726	78	8.4	83	2025	78	0.008*	79
PS-01	0.16	2	--	--	--	--	70	2	--	--
PS-02	0.35	50	--	--	4.2	34	427	33	--	--
SS-03	13.3	57	2020	44	6.5	45	1786	44	0.010*	43
SS-04	14.4	42	291	16	7.7	19	104	28	0.005*	11
SS-05	32.4	11	--	--	7.9	3	--	--	--	--
PS-04	0.45	10	--	--	7.6	7	167	10	--	--
PS-07	0.009	1	--	--	--	--	750	1	--	--
SS-06	35.2	7	--	--	8.3	5	46	1	--	--
PS-08	12.6	15	392	6	7.2	3	70	3	--	--
SS-07	37.3	15	1004	6	8.0	3	54	1	--	--
SS-08	37.9	4	--	--	8.0	3	58	1	--	--
PS-10	0.33	1	--	--	--	--	1470	1	--	--
SS-11	39.1	13	--	--	7.7	4	1265	2	--	--
SS-12	4.8	6	--	--	--	--	183	5	--	--
SS-14	46.1	54	734	53	7.8	55	474	52	0.010*	51
SS-15	11.9	16	152	6	--	--	27	6	--	--
SS-16	63.9	71	682	62	8.0	63	377	57	0.011*	53
SS-17	63.0	84	1069	55	7.8	74	455	75	0.012*	72
SS-19	101.7	14	--	--	7.8	10	57	15	0.018*	2
PS-12	107.8	382	1060	212	8.3	337	444	358	0.013	335
SS-28	71.7	43	797	9	7.9	12	161	37	0.003	2
SS-29	215	29	--	--	8.1	7	132	24	0.011	25
SS-32	368	55	--	--	8.1	3	213	58	0.018*	56

TABLE 3-1
MEAN VALUES OF PUBLISHED AND UNPUBLISHED HISTORIC DATA
(1975 - 1985) COMPARED TO FEDERAL DRINKING WATER STANDARDS[a,b] (Continued)

Station	Cadmium (mg/L)		Copper (mg/L)		Iron (mg/L)		Manganese (mg/L)		Lead (mg/L		Zinc (mg/L)	
	$\bar{x}$	N	$\bar{x}$	N	$\bar{x}$	N	$\bar{x}$	N	$\bar{x}$	N	$\bar{x}$	N
Federal Standard[c]	0.01	--	1.0	--	0.3	--	0.05	--	0.05	--	5	--
SS-02	0.002*	78	0.22*	90	0.260*	89	--	--	0.006	78	0.84*	88
PS-01	--	--	9.4	2	91	2	35	2	--	--	28	2
PS-02	0.43	1	6.1	14	47	15	4.2	9	--	--	15	15
SS-03	0.007*	52	0.56*	30	2.23*	48	--	--	0.009*	44	1.13*	57
SS-04	0.001*	25	0.053*	43	.701	27	0.193	3	0.0006	17	0.072	29
SS-05	--	--	0.195*	11	1.44*	11	--	--	--	--	0.411*	11
PS-04	--	--	0.254*	10	0.670*	10	--	--	--	--	3.44*	10
SS-06	--	--	0.467*	6	2.10*	6	--	--	--	--	0.845*	6
PS-08	0.004	9	0.111*	12	0.254*	5	--	--	--	--	0.659*	14
SS-07	0.019*	9	0.309*	14	1.14*	5	--	--	--	--	1.82*	14
SS-08	--	--	0.153*	3	0.853*	3	--	--	--	--	0.403*	3
PS-10	--	--	0.020*	1	0.090*	1	--	--	--	--	0.020*	1
SS-11	--	--	0.528*	13	2.45*	13	--	--	--	--	1.17*	13
SS-12	--	--	--	--	0.340*	3	0.200	2	--	--	0.045	6
SS-14	0.002	53	0.440*	53	1.89*	53	--	--	0.015*	53	1.161*	53
SS-15	0.001*	9	0.005*	15	0.184	4	2.99	2	--	--	0.045	6
SS-16	0.002*	66	0.365*	74	1.63*	65	--	--	0.011*	57	1.03*	74
SS-17	0.001*	9	0.436	72	1.93	72	--	--	0.026*	71	1.22	72
SS-19	0.001*	5	0.362*	14	0.812*	11	--	--	--	--	0.569*	13
PS-12	0.001*	25	0.056	341	0.277	332	--	--	0.0038	333	0.127	340
SS-28	0.001*	21	0.011*	38	0.110	25	--	--	--	--	0.011*	39
SS-29	0.001*	14	0.028	28	0.331	29	0.482*	6	0.0085*	26	0.072*	29
SS-32	--	--	0.052*	57	0.486	57	0.250*	56	0.00831*	12	0.098*	57

(a) * indicates total recoverable
(b) $\bar{x}$ = mean, N = number of observations. In calculating means, observations with values reported as less than a detection limit were set to zero (0).
(c) USEPA 1976, 1985a-d, 1986

The concentrator discharge, as measured at SS-02, contained concentrations of metals that were generally below drinking water standards. The high pH of the concentrator discharge (10.6 s.u.) was from lime treatment used to remove metals.

Historic measurements near the lower end of the MSD (SS-03; Map 1-2 Over Size) show an average flow of 13 cfs (with a maximum of 25 cfs) (Table 3-1). These figures compare to a range of 0.27 to 1.10 cfs in fifteen sampling episodes during the RI. Historically, high levels of sulfate (1786 mg/L) and pH (9.8) persisted in the lower MSD.

Two contributing storm drains, PS-01 (Warren Avenue) and PS-02 (Harrision Avenue) (Map 2-1), were sampled occasionally and showed combined average flows of about 0.50 cfs. The Anaconda Minerals Company (AMC) took grab samples in 1979 from these two contributing storm drains. Maximum flows reported for PS-01 and PS-02 were 0.28 cfs and 0.56 cfs, respectively; hence, the samples apparently were not taken during major storm runoff events. During the RI storm run-off sampling episode of May 29, 1985, these two point sources contributed 33.3 cfs.

According to an AMC technical memorandum (Colvin 1979), PS-02 flowed continuously due to ground-water leakage from the Kelly Shaft pumps (pumping was discontinued in April of 1983) and discharge of scale-laden water from cleaning of the heating plant boilers. The pH at PS-02 varied between 2.8 and 9.8, depending on the relative discharges of the two sources. Total recoverable copper loads averaged

11 lb/day, and zinc loads averaged 28 lb/day over the study period. These loads were significant additions to the MSD at that time. Historic metal loads in Silver Bow Creek are best calculated from the unpublished data of AMC in 1976 and 1977 and the data of Beuerman and Gleason (1978) in 1977. These studies collected same-day samples at several points along Silver Bow Creek. Table 3-2 summarizes average loads based on these studies for total recoverable copper and zinc for Silver Bow Creek stations.

TABLE 3-2
HISTORIC AVERAGE COPPER AND ZINC LOADS IN SILVER BOW CREEK

STATION	AMC DATA (1976-77) TOTAL RECOVERABLE LOAD (LB/DAY)		BEUERMAN AND GLEASON (1978) DATA FROM 1977 TOTAL RECOVERABLE LOAD (LB/DAY)	
	COPPER	ZINC	COPPER	ZINC
SS-02	7	6	--	--
SS-03	21	38	22	50
SS-04	4	9	<1	<1
SS-05	26	68	--	--
SS-07	--	--	61	460
SS-11	86	284	--	--
SS-16	85	247	119	399
SS-17	--	--	139	372

Both the AMC and Beuerman and Gleason studies attributed the increase in load between stations SS-02 and SS-03 on the MSD to the contributory storm drain inflow. If the loads calculated from the data of Colvin (1979) for the storm drain PS-02 are added to the load measured by AMC at SS-02, the results are just less than the loads measured at SS-03 (Map 1-2 Over Size). Therefore, storm drain inflows account for most of the increase in load in this reach of

the MSD, and the influences of ground-water discharge were relatively minor at this time. Loads of total copper and total zinc calculated for SS-03 during RI low-flow periods were 1.6 and 15.8 lbs/day, respectively. During RI high-flow periods, SS-03 contributed 6.9 lbs/day copper and 47 lbs/day zinc.

Historically, lower Blacktail Creek (SS-04; Map 1-2 Over Size) diluted the stormdrain discharge with about 14 cfs of comparatively good quality water (Table 3-1). During the RI study period Blacktail Creek averaged 15 cfs, ranging from 8.15 to 38.7 cfs.

Measured loads in the studies of Beuerman and Gleason (1978) and Peckham (1979) show considerable variation between sampling events. Total recoverable copper loads resulting from the Weed Concentator discharge (SS-02; Map 1-2 Over Size) varied from 1.3 to 20 lb/day, and zinc loads varied from 3 to 10 lb/day. Loads at SS-05, the first station below the MSD (Map 1-2 Over Size) showed a much greater variation, but did not vary directly with site SS-02. These load variations in Silver Bow Creek were probably due to runoff events and contributions from ungaged and unsampled sources.

Historic point-source sampling showed measurable total recoverable copper, iron, and zinc concentrations originating at Missoula Gulch (PS-04) (Map 1-2 Over Size; Table 3-1). Occasionally high total recoverable zinc concentrations (maximum of 3.2 mg/L) were found in the Butte Sewage Treatment Plant (STP) discharge (PS-08). High

zinc values in the STP discharge probably were a result of ground-water pumping during construction at the STP from 1977 to 1979. According to Peckham (1979), a ground-water drain used to de-water the construction area discharged directly to Silver Bow Creek. At that time, this drain discharged an average of 0.18 cfs of water, with the quality shown in Table 3-3. Zinc concentrations of this ground-water discharge were exceptionally high and indicate a significant contaminant source.

TABLE 3-3
AVERAGE TOTAL CONCENTRATIONS OF GROUND-WATER
DRAIN AT BUTTE STP (PS-08), OCTOBER 1978

Cadmium	0.08 mg/L
Copper	0.10 mg/L
Iron	0.97 mg/L
Zinc	29 mg/L
Chloride	29 mg/L
Sulfate	590 mg/L

Source: Peckham 1979.

Only total recoverable cadmium (0.19 mg/L) exceeded primary drinking water standards at SS-07, below the Colorado tailings. Zinc also increased in this reach, attaining a mean of 1.8 mg/L at SS-07. Average specific conductance at station SS-07 was 1004 umhos/cm; average pH was 8.2 (Table 3-1). Fifteen measurements of discharge at SS-07 during July to September 1977 averaged 37.3 cfs, ranging from 21.2 to 48.6 cfs. During the RI period, discharge at SS-07 averaged 26.5 cfs, ranging from 19.6 to 55 cfs.

Averaged data in Table 3-2 show general increases in total recoverable copper and zinc load in Silver Bow Creek below the MSD. The high zinc load at SS-07 (Map 1-2 Over Size) is probably due to ground-water pumping during construction activities at the Butte STP. Although the discharge measured by Peckham in 1979 only contributed about 28 lb/day of zinc, Beuerman and Gleason's data (1978) on the Butte STP discharge showed occasional zinc loads of hundreds of pounds per day. According to Bill Pascoe (1985), the Butte STP operator, ground water was discharged in addition to that measured by Peckham, and this water was routed into the STP discharge at times.

3.1.1.2 Lower Silver Bow Creek

Table 3-1 shows the water in lower Silver Bow Creek had specific conductivities of about 900 µmhos/cm, high for a western Montana stream, and pH was above 7.0. The high average sulfate concentration reported at SS-11 (1,265 mg/L) is based on only two data points. Peckham's 1979 data show no evidence of such high sulfate concentrations anywhere on Silver Bow Creek below the MSD.

Prior to suspension of activities at AMC's Butte Operations in 1983, irregular discharges occurred from the Silver Lake pipeline between stations SS-10 and SS-11 (Peckham 1979). Averaged historic data show no evidence of a flow increase at this site. Historic flow data at SS-11 (13 data points) averaged 39.1 cfs and had a maximum of 57.6 cfs (August - October 1976, April - June of 1977,

and May and August of 1979). During the RI period average flows at SS-11 were 37.5 cfs, ranging from 21.5 to 55.4 cfs.

Average metal concentration on this stretch of Silver Bow Creek, measured as total recoverable metals, were less than drinking water standards for all measured parameters except iron (Table 3-1). Browns Gulch (SS-12) showed an average manganese concentration of 0.20 mg/L, much higher than the drinking water standard of 0.05 mg/L. Load information for copper and zinc, summarized in Table 3-2, shows that they generally increased.

Historic flows (instantaneous measurements) averaged 46 cfs at SS-14 (ranging from 20 to 112 cfs) and increased to an average of 64 cfs at SS-17 (ranging from 30 to 140 cfs) (Table 3-1). Much of the increase in flow is attributable to the entry of German Gulch (SS-15) into the canyon between stations SS-14 and SS-16. Flows at SS-14 during the RI period averaged 43.8 cfs and ranged from 23.6 to 57.8 cfs. Flows at SS-16 during the RI period averaged 57.8 cfs, ranging from 25.2 to 88.3 cfs.

No major changes in field parameters or sulfate occurred in this reach. Average metal concentrations, except for iron, did not exceed Federal drinking water standards (Table 3-1). However, a very high manganese reading (5.97 mg/L) was reported on German Gulch; this raised the average manganese concentration at SS-15 to a value well above the Federal drinking water standard. This high

measurement was not caused by high flow, and no explanation for it was apparent.

SS-17 (located above the Warm Springs Ponds) had an average historic flow of 63 cfs (84 data points), ranging from 12.9 to 154 cfs. During the RI period, flows at SS-17 averaged 62 cfs and ranged from 22.7 to 88.8 cfs.

3.1.1.3 Downstream of Warm Springs Ponds

Beyond the Warm Spring Ponds, a number of tributary streams are present, but historic data were available only for Warm Springs Creek (SS-28). Some historic data are available for the Clark Fork River at Perkins Lane Bridge (SS-29), a short distance below the confluence of Warm Springs Creek. Most of the data are reported by the Montana Department of Health and Environmental Sciences (MDHES), Water Quality Bureau (WQB), for its permanent water quality station located on the Clark Fork River at Deer Lodge (SS-32; Map 1-5).

Flows on the upper Clark Fork River were much larger than those of Silver Bow Creek (Table 3-1), because of inflows from Mill, Willow, and Warm Springs creeks, and additional tributaries downstream. Water quality was generally good; average metals concentrations were below Federal drinking water standards, except for manganese (Table 3-1). However, arsenic and lead occasionally exceeded Federal drinking water standards.

Load data were not available at consecutive stations on the same day prior to the suspension of activities at AMC's Butte Operations in 1983. The WQB's Clark River Survey and its sampling run of April 1983 provide some loading data for this reach, as presented in Table 3-4. This table also shows RI data for comparison.

TABLE 3-4
HISTORIC AND RI COPPER AND ZINC LOADS (LB/DAY) ON THE CLARK FORK RIVER

Date	SS-29		SS-32		SS-36	
	Copper	Zinc	Copper	Zinc	Copper	Zinc
04/28/83 (WQB)	65	100	120	120	150	170
06/27/84 (WQB)	116	120	430	590	--	--
05/23/85 (RI)	140	41	110	84	66	30
06/20/85 (RI)	7	10	7	7	30	25

Data from the April 1983 run are total metals; those from June 1984 are total recoverable metals. However, the increase in load between SS-29 and SS-32 is clearly much larger during the June 1984 event. The flow data for these dates are summarized on Table 3-5.

TABLE 3-5
FLOW (cfs) ON THE CLARK FORK RIVER

Date	SS-29	SS-32	SS-36
04/28/83 (WQB)	243	358	385
06/27/84 (WQB)	720	997	--
05/23/85 (RI)	263	293	223
06/20/85 (RI)	55	66	81

3.1.2 Nutrient Concentrations

Average nutrient concentrations from the selected published and unpublished historic data are summarized in Table 3-6, and average nutrient loads are shown in Figures 3-1 and 3-2. The data are those of Beuerman and Gleason (1978), except for station SS-32 on the Clark Fork River (Montana Department of Health and Environmental Sciences, collected mostly in 1979). The Butte STP (PS-08; Map 1-2 Over Size) apparently was a major source of phosphorus and Kjeldahl nitrogen. Blacktail Creek (SS-04; Map 1-2 Over Size) was also a major contributor of nitrate.

Nutrient concentrations and loads generally decrease downstream (Table 3-6 and Figures 3-1 and 3-2). Figure 3-1 shows that total phosphorus load remains constant from SS-07 to SS-16 and decreases between SS-16 and SS-17. Kjeldahl nitrogen loads decrease from SS-07 to SS-17 (Figure 3-2).

Nutrient loads on the Clark Fork River at Deer Lodge are much larger than the sum of the loads from the Warm Springs Ponds discharge and Mill, Willow, and Warm Springs creeks (see Figures 3-1 and 3-2). Apparently, the upper Clark Fork River has other major sources of nutrients.

TABLE 3-6
AVERAGE VALUES OF NUTRIENTS IN HISTORIC DATA (1975-1985)

STATION	ORTHOPHOSPHATE (as P, mg/L)	TOTAL PHOSPHORUS (as P, mg/L)	NITRATE (as N, mg/L)	KJELDAHL NITROGEN (mg/L)
Federal Drinking Water Standards	---	50	10	--
SS-03	3.8	4.5	0.05	15
SS-04	0.094	0.31	3.9	0.4
PS-08	3.8	4.5	0.05	15
SS-07	0.83	1.2	1.1	4.8
SS-15	0.042	0.11	0.012	0.24
SS-16	0.31	0.83	1.4	2.2
SS-17	0.16	0.63	1.9	1.7
PS-12	0.005	0.028	0.21	0.46
SS-25	0.011	0.22	0.10	0.32
SS-28	--	0.16	--	0.40
SS-32	0.70	0.083	--	0.43

FIGURE 3-1

TOTAL PHOSPHORUS LOAD (lb/day) FOR AVERAGED HISTORIC DATA

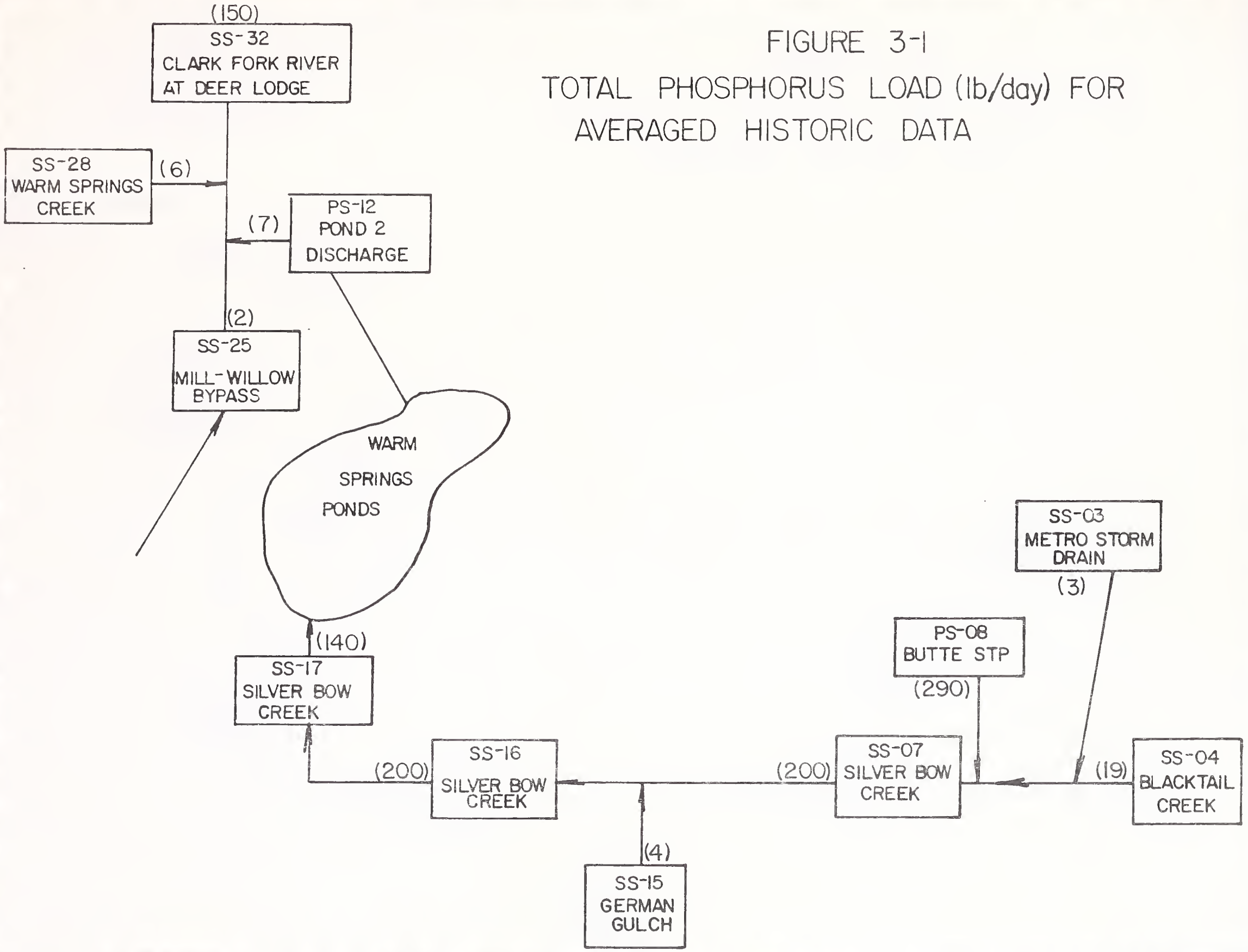
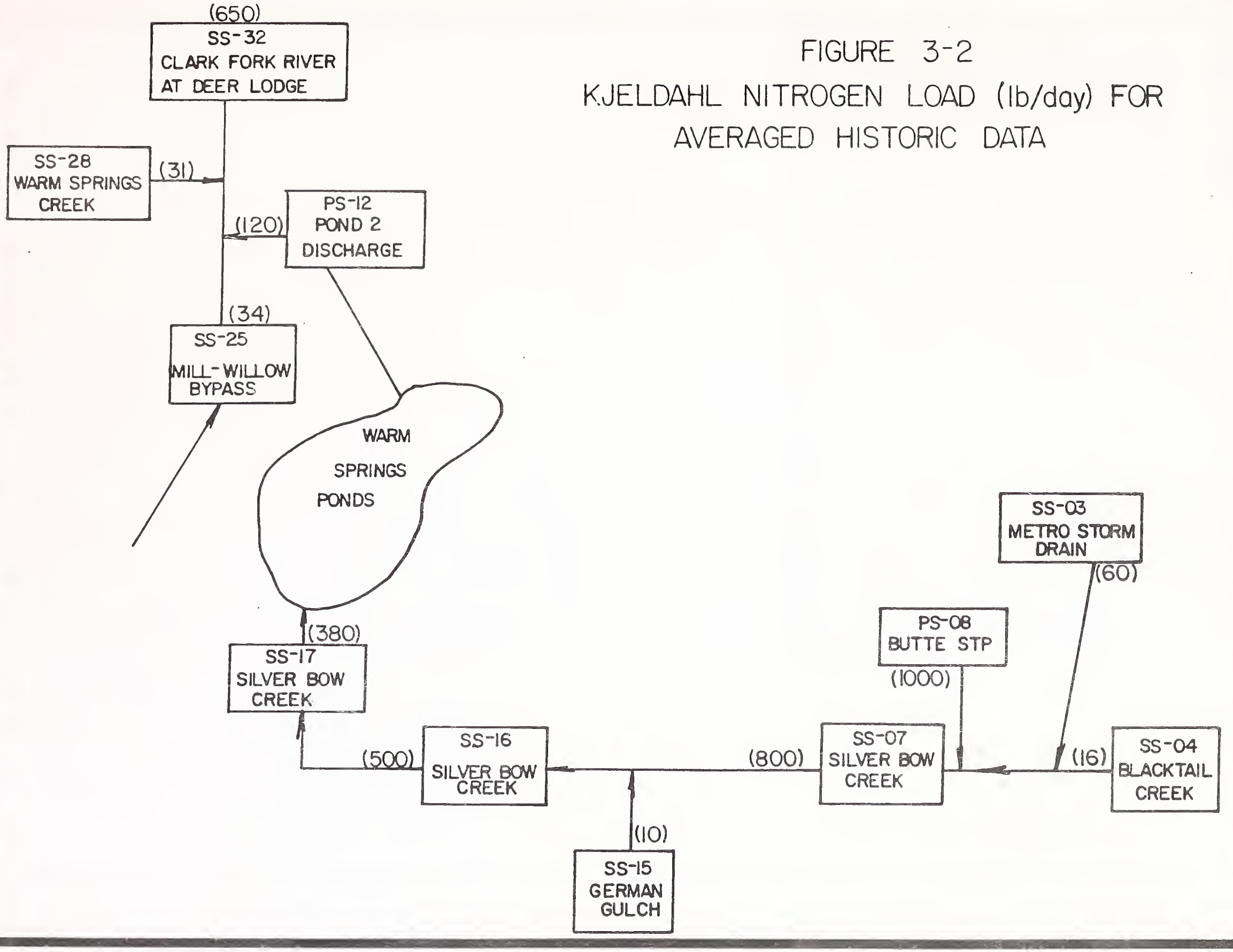


FIGURE 3-2
KJELDAHL NITROGEN LOAD (lb/day) FOR AVERAGED HISTORIC DATA



3.1.3 Flow

Table 3-7 presents flow data along the main stem of Silver Bow Creek (SS-03 to SS-17) and compares averaged historic data to averaged RI data. To make the data comparable, the RI data was adjusted upstream of the Silver Lake Discharge. During the historic period, water from Silver Lake was diverted to the concentrator in Butte and discharged into the MSD. This water was discharged at PS-11 during the RI. Those stations affected by this change (SS-03 through SS-08) were adjusted by adding the average RI flow at PS-11 (12.8 cfs) to the average RI flow at each station.

This adjusted flow is then comparable to the historic flow. Table 3-7 also lists the differences between average historic flows and adjusted RI flows in both cfs and percent. The comparison shows RI flow data to be very close to that generated historically. Differences range $\pm$ 6 cfs (-16 to +10%) between historic and RI flows. The comparison does not include the distribution of flows over the year. While average flows were similar, minimum and maximum flows were not. When compared to 1985 RI data, historic flows were higher in the spring and lower in the summer. This indicates that hydrologic conditions represented by the RI data, while distributed differently, are probably representative of recent (post-1975) conditions on Silver Bow Creek.

TABLE 3-7
COMPARISON OF HISTORIC AND RI FLOW DATA

STATION	AVERAGE HISTORIC FLOW (CFS)	AVERAGE RI FLOW (CFS)	ADJUSTED[a] RI FLOW (CFS)	DIFFERENCE (CFS)	DIFFERENCE %[b]
SS-03	13.3	0.5	13.3	0	0
SS-04	14.4	14.9	--	0.5	3.5
SS-05	32.4	15.3	28.1	-4.3	-13.3
SS-06	35.2	16.7	29.5	-5.7	-16.2
SS-07	37.3	26.5	39.3	2.0	5.4
SS-08	37.9	26.2	39.0	1.1	2.9
PS-11	0	12.8	0.0	0	0
SS-11	39.1	37.5	--	1.6	4.1
SS-14	46.1	43.8	--	2.3	5.0
SS-16	63.9	57.8	--	6.1	9.5
SS-17	63.0	61.1	--	1.9	3.0

(a) Adjusted for the Silver Lake Discharge (see text).

(b) Percentage of historic flow.

3.2 RI DATA

All RI data used in this evaluation are included in Attachment IV. Prior to any discussion, the quality of the RI data must be examined. Quality Assurance/Quality Control (QA/QC) data generated by the laboratory for both laboratory and field duplicates were included with each lab report and are compiled, averaged, and presented in Table 3-8. Absolute values of percent deviation were used in calculating the average percent deviation. Precision is important when comparing data points within any one study; accuracy is important when comparing data from different studies. Since only RI-generated data were used in this evaluation, precisions are most important and are presented in the table. These data were used to determine the resultant precision of loading calculations. QA/QC procedures show the RI data to be very precise (reproducible), and the resulting load calculations to be very precise also. With this data quality information, RI data can be interpreted within a known confidence interval. Differences less than that confidence interval were ignored unless the observation was consistent, recalling that the confidence about a mean (x) is greater than that about any individual measure (Sec. 2.3.1.2).

The data collected for this RI represented conditions during the period December 1984 through August 1985. This period was drier than average for Butte and may not be representative of typical conditions on Silver Bow Creek. Table 3-9 presents monthly precipitation data for the RI study period and compares them to averages for the Butte

TABLE 3-8
SBC RI SURFACE WATER DATA QA/QC SUMMARY[a]

Parameter Measured[b]	Average Lab Precision (R_A)	Average Field Duplicate Precision (R_D)	Average Precision of Load Calculations (R_L)[c]
	±%	±%	± %
Sulfate	1.9	2.7	3.5
Cu (D)	2.8	5.5	5.9
(T)	3.1	6.9	7.2
Zn (D)	1.7	5.5	5.9
(T)	2.4	3.5	4.1
Fe (D)	2.4	7.1	7.4
(T)	2.8	6.9	7.2
As	4.7	8.2	8.5
Pb	4.4	8.2	8.5
Cd	4.9	6.3	6.7
pH	--	0.7	------
Flow (R_F)	--	2.2	------

Notes:

(a) From Appendix F, Quality Assurance/Quality Control Summary

(b) D = dissolved, T-total

(c) $R_L = \sqrt{(R_F)^2 + (R_D)^2}$

TABLE 3-9
PRECIPITATION DATA FROM BUTTE, MONTANA
(in inches)

MONTH	AVERAGE[a] PRECIPITATION	RI STUDY PERIOD PRECIPITATION[b]	DEPARTURE FROM AVERAGE INCHES	DEPARTURE FROM AVERAGE PERCENT(%)
November 1984	.49	.62	+.13	+27
December	.48	.26	-.22	-46
January 1985	.42	.17	-.25	-60
February	.44	.34	-.10	-23
March	.65	.69	+.04	+6
April	.90	.18	-.72	-80
May	1.74	1.66	-.08	-5
June	2.42	1.22	-1.20	-50
July	1.20	.33	-.87	-73
August	1.03	1.52	+.49	+48
TOTAL	9.77	TOTAL 6.99	TOTAL -2.78	-28

Note:

(a) Averages for the period 1931 to 1960 (NOAA, 1971)

(b) NOAA 1985

area. Precipitation was particularly low for January, April, and July, but was higher than average for August. Overall, precipitation was 28% less than average during the RI study period.

Mountain snowpack is also important to the hydrologic behavior of Silver Bow Creek. Table 3-10 lists the water content of 1985 snowpack as a percent of average. The table shows that early 1985 had greater than average water content in the snowpack, but an early melt and extremely low precipitation in April reduced water content in the snowpack to well below average.

TABLE 3-10
1985 SNOWPACK WATER CONTENT DATA FROM AROUND BUTTE, MONTANA
(PERCENT OF AVERAGE WATER CONTENT 1961-1980)(a)

Measurement Date (1985)	Basin Creek Station	Pipestone Pass Station	Moulton Reservoir Station
Jan. 1	137	122	113
Feb. 1	117	87	131
Mar. 1	107	105	87
Apr. 1	112	95	116
May 1	82	83	0
May 15	56	--	--

Note:

(a) USDA Soil Conservation Service, 1985.

The below-normal precipitation is reflected in the hydrographs of Silver Bow Creek and the lower Clark Fork River (Attachment V).

Attachment VI lists USGS daily measurements on Silver Bow Creek and the upper Clark Fork River. These records show the period May through August as having unusually low flows. Some of these low flows may be exaggerated by irrigation withdrawals. Although no long-term records are available on Silver Bow Creek, records are available for Water Year 1984 for the Texas Avenue gage and Silver Bow Creek below Blacktail Creek. Comparison of the two years of record show lower flows on upper Silver Bow Creek in 1985 for May and June.

The effects of the lower precipitation and flows include fewer runoff events that wash contaminants into the creek and fewer high flow events that erode bank material and scour the creek bottom, removing previously settled solids. Although these events were fewer in number, they did still occur. One such event was sampled on May 29 as the storm runoff event, and another regular sampling (June 3-5) followed a 24-hr. rainfall of more than 1 inch.

These runoff events, while more frequent in normal years, were sampled and quantified during the RI. The results of this study can be used to help predict runoff effects in normal or wet years. Conversely, lower flows and rainfall can be used to study the effects of ground-water inflows, since surface-related effects are subdued.

Although precipitation for 1985 was below average, it was a typical year. Years that are as dry as 1985 are well within one standard

deviation of the average. This means drier years, like 1985, are quite common in the Butte area. Precipitation was distributed differently during 1985 than in average years, with less occurring in spring and more during late summer. This difference reduced peak flows in Silver Bow Creek during the study.

Additionally, the RI data represents a unique set of data, in that the Weed Concentrator was not discharging to Silver Bow Creek. The data collected during the RI therefore represent the lasting effects of past mining in the Summit Valley.

3.2.1 Data Segregation

The temporal trends observed in the flow data show four distinct hydrologic flow regimes on Silver Bow Creek (see Table 2-3):

(1) Winter baseflow, sampling runs 2-4 (Dec 26 - Feb 11)

(2) Snowmelt runoff, runs 7-10 (Mar 25 - May 6)

(3) Storm runoff, run 12 (June 3)

(4) Summer baseflow, runs 14-15 (July 22 - Aug 27)

The tributary streams to Silver Bow Creek had different dates for these flow regimes, but showed the same patterns. The divergence merely reflects that hydrologic events vary at different places: precipitation, snowmelt, base flows, etc.

The differences in flow and contaminant behavior between runoff and baseflow are quite distinct, while within each of the runoff and

baseflow regimes differences are subtle. For most analyses in this report, summer and winter base flows are combined as "Low Flow", and the snowmelt and storm runoffs are combined as "High Flow."

The storm runoff sampling of June 3-5 represents a unique set of data in which samples were collected following rainfall of 1.05 inches (measured at the Butte airport) in the previous 24 hours. This rainfall was nearly equal to the statistical 2 year-24 hour storm event. Flows on Silver Bow Creek were generally the highest of any of the sampling runs, yet flows from uptown Butte (SS-03, Metro Storm Drain and PS-04, Missoula Gulch) were at baseflow levels. This difference means that contaminant contributions from Butte runoff are minimized, while the high flow in the creek still affects bedload movement and bank erosion; these fluvial processes then can be studied independently of surface runoff effects from uptown Butte.

3.2.2 Flow Gains

Figure 3-3 schematically depicts flow inputs along the Silver Bow Creek system. Table 3-11 lists the relative contribution of each of the measured tributaries to Silver Bow Creek during the RI study period.

The table shows that the MSD and Missoula Gulch contribute relatively little water to Silver Bow Creek, while other sources are significant tributaries, especially during high flows. Several other

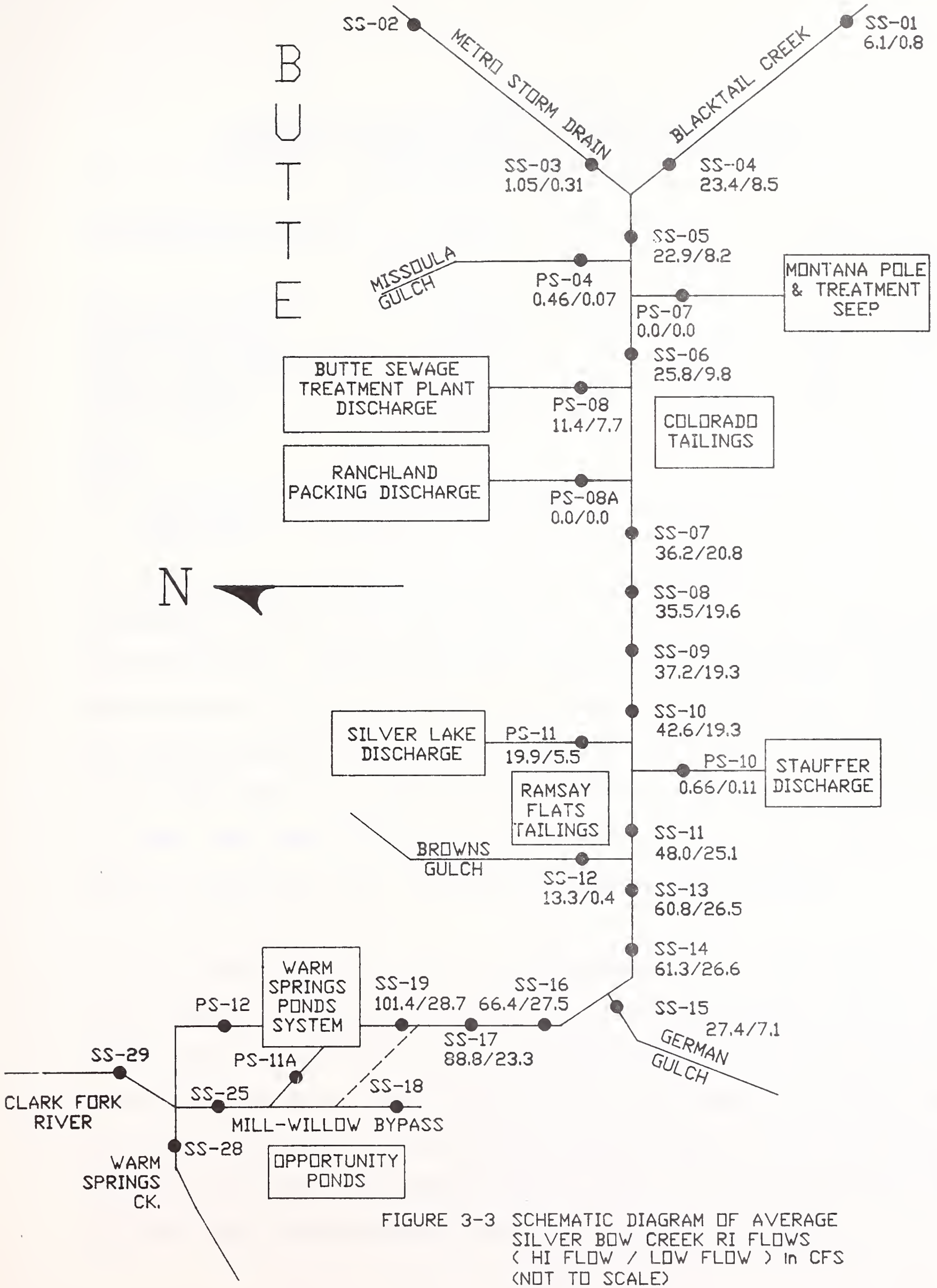


FIGURE 3-3 SCHEMATIC DIAGRAM OF AVERAGE SILVER BOW CREEK RI FLOWS
(HI FLOW / LOW FLOW) In CFS
(NOT TO SCALE)

TABLE 3-11
RELATIVE CONTRIBUTIONS OF WATER VOLUME FROM
MEASURED INPUTS, EXPRESSED AS AVERAGE PERCENTAGE
OF FLOW AT THAT POINT

Contributing Source	Station	Low Flow		High Flow	
		cfs	%(a)	cfs	%(a)
Metro Storm Drain	(SS-03)	0.31	2.0	1.05	4.7
Missoula Gulch	(PS-04)	0.07	0.5	0.46	2.9
Sewage Treatment Plant	(PS-08)	7.7	33.0	11.4	27.0
Silver Lake Discharge	(PS-11)	5.5	18.3	19.9	44.1
Browns Gulch	(SS-12)	0.4	1.2	13.3	21.0
German Gulch	(SS-15)	7.1	15.1	27.4	35.0

Note:

(a) Expressed as a percentage of flow at the confluence with Silver Bow Creek

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unmeasured inflows to the creek are apparent upon examination of the RI data. Table 3-12 lists significant unaccounted inflows, which may be from ground water or unmeasured surface-water inflows. The low-flow condition is most representative of ground-water inflow, while high flow is a combination of ground-water and surface-water inflows. The relationship of the different unaccounted sources of water is important when interpreting metals-loading data.

Another less important source of flow variation is bank storage. A small amount of water will go into the stream banks during high flows and then slowly re-enter the creek during lower flow periods. Therefore, the first sampling following high flows may reflect some bank dewatering and not true ground-water input. For this reason, episodes following high flows (Runs 11 and 13, May 20 and June 17) were not used in evaluating sources of unaccounted water.

TABLE 3-12
AVERAGE FLOW GAINS FROM UNACCOUNTED SOURCES

Stream Section	Low Flow			High Flow		
	Flow Gain (cfs)	%(a)	Number of runs	Flow Gain (cfs)	%(a)	Number of runs
SS-05 to SS-06	1.7	19.5	3	2.7	13.6	5
SS-06 to SS-07	1.4	7.1	6	0.3	0.6	5
SS-08 to SS-09	0.2	0.8	7	1.7	5.9	5
SS-09 to SS-10	0.6	2.6	5	1.3	2.4	5
SS-10 to SS-11	1.4	5.8	3	1.6	3.3	3
SS-11 to SS-13	1.4	6.2	2	2.3	3.6	5

Note:

(a) Expressed as a percentage of flow gained with respect to flow at the upstream station.

Examination of the flow changes presented in Table 3-12, the topographic maps of the area (Oversize Maps 1-2, 1-3, and 1-4), and some of the chemical information generated during the RI allows a determination of the probable source of these additional waters.

3.2.2.1 SS-02 to SS-03 (Metro Storm Drain)

During low flow, SS-02 was always dry, hence all the flow measured at SS-03 came from either contributing storm drain outflows or ground water. The Harrison Avenue outfall (PS-02) was observed contributing minor flow into the MSD during most sampling runs, but measurements were not performed, so determining the exact contribution from PS-02 is not possible. Chemical data from the MSD and ground-water samples collected near the MSD suggest significant ground-water contributions.

3.2.2.2 SS-05 to SS-06 (Montana Street)

Flow increases in the reach between SS-05 and SS-06 were primarily from ground-water inflows. Additional water entered during high flow events, but this could be additional ground water or small surface inputs. Summmer seepage runs showed most of the increase occurs between stations SS-05A and SS-06. The water chemistry also supports ground-water inflow. At least two possible sources exist for this inflow: ground water associated with the Missoula Gulch alluvial system could be entering Silver Bow Creek through the historic channel alluvium, or ground water from the MSD or Blacktail Creek alluvial systems could be surfacing in this stretch. (See the Ground Water and Tailings Report, Appendix B, for further discussion).

3.2.2.3 SS-06 to SS-07 (Colorado Tailings)

The next reach of Silver Bow Creek shows a consistent gain during low flows and probably represents a continuation of the previous ground-water inflow. This flow gain and significant increases in dissolved metals suggest a ground-water input which is masked during higher flows. This input is important as a source of metals, discussed later in this report and in Appendix B.

3.2.2.4 SS-08 to SS-09 (Rocker to Nissler Junction)

From SS-08 and SS-09, Silver Bow Creek shows significant gains in water during high flows, which is interpreted to be from ungaged surface sources. Between these stations, Gimlet Gulch (north) and Canada Creek (south) enter Silver Bow Creek. Surface and/or ground water from either could account for the gain observed during high flows.

3.2.2.5 SS-09 to SS-10 (Nissler to Silver Bow)

Flow gains are observed between SS-09 and SS-10 during both high and low flows. Three unnamed drainages enter Silver Bow Creek in this stretch and could account for the increase. Ground-water inflow from these drainages is probably causing the small increases in flow.

3.2.2.6 SS-10 to SS-11 (Silver Bow to Ramsay Flats)

The gains between SS-10 and SS-11 are calculated using only data generated on or after March 25, when both stations were gaged on the same day at nearly the same time. Though the gains are near the accuracy of the instrument, they are consistent between sampling runs and, as described in Chapter 2, the accuracy of the mean is an improvement over each individual measurement. Seepage run data shows the gain to be between stations SS-10 to SS-10A and between SS-10B and SS-11. These stretches correspond to two surface water

inputs, Sand Creek (ungaged) and an unnamed drainage flowing past Stauffer Chemical (PS-10), each of which has an alluvial ground-water system associated with it. Flow gains can be explained by these two surface- and ground-water systems.

3.2.2.7 SS-11 to SS-13 (Ramsay Flats)

This stretch from SS-11 to SS-13 shows significant gains during both high and low flows. Ungaged surface or ground water from Price Gulch and ground water from the Browns Gulch alluvial system probably account for these gains.

3.3 SOURCES OF CONTAMINATION

Many of the actual sources of contamination could not be traced to their origins because they are outside the study area. This is particularly true in the Butte area, where historic and inactive mine dumps, tailings, pits and shafts, and the concentrator are all offsite. The extensive tailings that lie alongside Silver Bow Creek and the Clark Fork River probably originated at offsite sources in and around Butte (as well as lesser contributions from the old works located along Warm Springs Creek), but they have existed for as long as a century at their present locations and can be considered sources in their own right. In this discussion the word "source" often means the source to the stream or pathway rather than the ultimate source, and the reference is explained for each discussion.

Analysis of data collected on Silver Bow Creek during this RI shows it to be severely impacted by metals contamination. The sources of these metals and their relative impacts on Silver Bow Creek water quality are discussed in this section. Two types of sources will be discussed separately:

(1) Measured point sources evaluated specifically in this RI.

(2) Non-point sources, such as stream bank erosion or ground-water inflow.

For non-point sources, most of the effects on Silver Bow Creek are inferred from data trends between stations and are indirect measures. Though impractical and expensive to directly monitor all these potential sources, their evaluation is still possible using the data gathered for the RI.

For the purposes of this discussion, the effects on Silver Bow Creek are usually stated as percent contribution. This percentage is calculated as the amount contributed by a specific source as compared to the total upstream inputs. This calculation eliminates biases due to the various chemical and physical processes in the creek between the point of input and downstream measurement.

$$\%\text{contribution} = \frac{\text{load from input source of concern}}{\text{load contributed by all upstream sources}} \times 100$$

As discussed previously, the data were segregated into low-flow and high-flow periods. In addition, the storm runoff sampling of May 29 and the high runoff event of June 3-5 were analyzed separately from the other sampling runs to determine the effects of high runoff and very high flow in Silver Bow Creek following significant precipitation. The storm event sampling occurred during a 0.38-inch rainfall lasting 1.5 hours on May 29, beginning at 1:00 p.m. The magnitude of this storm was slightly less than the statistical 1 year-2 hour storm event of 0.45-inch. The June 3-5 sampling episode followed total rainfall of 1.05 inches between June 1 at 5:00 a.m. and June 2 at 5 a.m. This rainfall is nearly equivalent to the statistical 2 year-24 hour precipitation of 1.18 inches. Clearly, the later storm was more significant in terms of runoff volume, and this is reflected in the data for the June 3-5 sampling. The May 29 data is difficult to integrate, because the same stations were not sampled as during regular sampling episodes. The runoff event, however, is quite useful in evaluating point sources, specifically the storm drains.

3.3.1 Measured Point Sources

3.3.1.1 SS-03 (MSD)

The MSD, because it is a relatively minor source of flow, will be treated as a point source merging into Blacktail Creek for this discussion. Table 3-13 lists the contribution of the MSD to loads

TABLE 3-13
LOADS CONTRIBUTED BY THE METRO STORM DRAIN (SS-03)

	LOW FLOW (Runs 1, 12, 14)		HIGH FLOW (Runs 7,8)	
	Load (lbs/day)	%(a)	Load (lbs/day)	%(a)
Flow	--	2.0	--	4.7
TSS	31.2	6.4(b)	138.1	8.0(b)
Sulfate	1150	24.5(b)	2554	33.8(b)
Cu (T)	1.6	33.8(b)	6.9	45.4(b)
Zn (T)	15.8	57.4(b)	47.0	87.1(b)
Fe (T)	9.5	16.3(b)	26.4	15.9(b)
As (T)	0.03	5.9(b)	0.07	5.8(b)
Pb (T)	0.09	18.2(b)	0.06	6.1(b)
Cd (T)	0.07	100.0(b)	0.18	100.0(b)

Notes:

(a) Expressed as a percentage of measurements at the confluence with Silver Bow Creek.

(b) Percent load contribution significantly higher than percent flow contribution, indicating degradation of Silver Bow Creek.

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measured in Silver Bow Creek. While accounting for a minor percentage of flow input, the MSD contributes significant amounts of zinc, copper, sulfate, iron, and cadmium to Silver Bow Creek during both high and low flows. Although the contaminant load added is small relative to other sources, the MSD is degrading water quality between SS-04 (Blacktail Creek) and SS-05 (Silver Bow Creek).

The area drained by the MSD is quite large, and specific contaminant sources are difficult to identify because only two stations were

sited in the area. Data collected during the storm event help to identify surface sources within the MSD system during high-flow, runoff conditions. Table 3-14 lists the percentage of flow and loads accounted for during the storm event as measured at SS-03. While only 22% of the flow was not accounted for, 55% to 80% of the metals loads are not accounted for. These unaccounted loads represent a significant, unmeasured source to the MSD during storm events.

TABLE 3-14
CONTRIBUTIONS TO THE MSD DURING THE STORM RUNOFF OF MAY 29, 1985, MEASURED AS A PERCENTAGE AT SS-03

	MSD AT				
	TEXAS AVENUE (SS-02)%	WALNUT STREET (PS-OA)%	WARREN AVENUE (PS-01)%	HARRISON AVENUE (PS-02)%	UNACCOUNTED LOADS%
Flow	5.0	39.0	3.3	30.0	22.5
TSS	1.1	13.3	5.0(a)	34.9(a)	45.7(a)
SO_4	27.0(a)	2.9	5.9(a)	34.9(a)	29.2(a)
Cu (T)	4.7	1.2	1.3	15.4	77.4(a)
Zn (T)	7.4(a)	1.1	3.7	31.3	56.4(a)
Fe (T)	0.6	5.0	2.6	21.4	70.4(a)
As (T)	0.7	7.2	4.7(a)	31.2	56.2(a)
Pb (T)	0.3	4.6	2.7	30.4	62.0(a)
Cd (T)	13.1(a)	3.1	3.0	22.9	57.9(a)

Note:

(a) Percent load contribution significantly higher than percent flow contribution, indicating that water quality is degraded.

As Table 3-14 shows, the area drained by SS-02 (upper MSD) contributes significant sulfate, zinc, and cadmium, while the Harrison Avenue drain (PS-02) contributes TSS and sulfate. The Warren Avenue drain (PS-01) contributes TSS, sulfate, and arsenic. Significant contaminant loads to the MSD during this runoff event were unaccounted. In addition to the storm sewer outfalls not measured (see Map 2-1), other possible sources are overland flow to the drain, shallow ground-water inflow, or mobilization of materials previously deposited in the drain.

3.3.1.2 PS-03 (Montana St.) and PS-05 (Kaw Avenue) Storm Drain Outfalls

Each of these outfalls was measured only once, during the storm event. The data represent high flow-runoff conditions only. Table 3-15 shows the Montana Street outfall (PS-03) contributes relatively good water to Silver Bow Creek, while the Kaw Avenue drain adds water with elevated TSS and arsenic. However, as these samples demonstrate, the impact of these two outfalls on water quality in Silver Bow Creek is minimal.

3.3.1.3 PS-04 (Missoula Gulch)

Missoula Gulch is also part of the storm drain system and is reported to contain numerous mining waste piles. Tables 3-15 and 3-16 list the loads contributed to Silver Bow Creek by the addition of Missoula Gulch. Again, Missoula Gulch adds minimal amounts

TABLE 3-15
LOAD CONTRIBUTIONS TO SILVER BOW CREEK DURING STORM EVENT SAMPLING OF MAY 29, 1985 MEASURED AS A PERCENTAGE OF LOADS AT SS-07

	PS-03 (Montana St.) %	PS-05 (Kaw Ave.) %	PS-04 (Missoula Gulch) %
Flow	4.6	12.3	12.1
TSS	3.8	16.2(a)	39.1(a)
Sulfate	1.6	10.2	12.6
Cu (T)	0.6	5.7	15.2(a)
Zn (T)	0.6	8.5	47.1(a)
Fe (T)	2.2	9.3	25.3(a)
As (T)	2.3	15.2(a)	32.8(a)
Pb (T)	3.9	9.7	18.8(a)
Cd (T)	1.4	7.1	40.9(a)

Note:

(a) Percent load contribution significantly higher than percent flow contribution, indicating that water quality is degraded.

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of flow and metals to the creek, but it significantly degrades water quality, especially during high flows. At low flows Missoula Gulch is a minor source of copper, zinc, lead, and cadmium. Higher flows turn Missoula Gulch into a source of TSS, copper, zinc, iron, arsenic, lead, cadmium, and sulfate to Silver Bow Creek.

3.3.1.4 PS-07 (Montana Pole Treatment Seep)

PS-07 contributes almost no flow to Silver Bow Creek and was dropped as a sampling station midway through the RI when emergency remedial clean-up of the Pole Treatment area was initiated by USEPA.

TABLE 3-16
LOAD CONTRIBUTED BY MISSOULA GULCH

	LOW FLOW (Runs 3, 9, 10)		HIGH FLOW (Runs 6-8)	
	Load (lbs/day)	%(a)	Load (lbs/day)	%(a)
Flow	--	0.5	--	2.9
TSS	7.5	0.7	605.6	32.3(b)
Sulfate	29.2	0.7	228.4	4.6(b)
Cu (T)	0.1	66.9(b)	1.6	17.8(b)
Zn (T)	0.5	4.7(b)	6.3	25.6(b)
Fe (T)	0.3	0.3	39.4	29.4(b)
As (T)	0.00	33.7(b)	0.10	14.9(b)
Pb (T)	0.01	35.6(b)	0.45	35.7(b)
Cd (T)	0.00	35.2(b)	0.02	68.0(b)

Notes:

(a) Expressed as a percentage of measurements at the confluence with Silver Bow Creek.

(b) Percent load contribution significantly higher than percent flow contribution, indicating degradation of Silver bow Creek.

Although PS-07 was a source of oil, grease, and PCP to the creek, ground-water impacts to the creek have not been evaluated.

3.3.1.5 PS-08 (Butte Sewage Treatment Plant-STP)

The STP did not display much seasonal flow variation during the RI. At certain times of the year, the STP pumps ground-water, significantly impacting water quality in Silver Bow Creek for brief periods. Table 3-17 lists loads contributed by the STP during normal opera-

TABLE 3-17
LOADS CONTRIBUTED BY THE STP (PS-08)

	NORMAL CONDITIONS (Runs 2-11, 13-15)		DURING GROUND-WATER PUMPING (Runs 1 & 12)	
	Load (lbs/day)	%*(a)	Load (lbs/day)	%*(a)
Flow	--	36.0	--	33.3
TSS	468	30.4	953.2	25.9
Sulfate	2361	29.3	6040	42.8(b)
Cu (T)	1.8	12.5	5.9	23.0
Zn (T)	4.3	11.6	279.9	82.6(b)
Fe (T)	8.70	11.0	9.0	6.1
As (T)	0.20	24.7	0.25	17.3
Pb (T)	0.14	33.2	0.22	27.6
Cd (T)	0.00	24.4	0.59	74.2(b)
OrthoPhosphate(c)	169.7	98.5(b)	--	
Total Phosphorous(c)	206.3	94.5(b)	--	

Notes:

(a) Expressed as a percentage of measurements at the confluence with Silver Bow Creek.

(b) Percent Load contribution significantly higher than percent flow contribution, indicating that water quality is degraded.

(c) One measurement only - February 25, 1985.

tions and during ground-water pumping (the December 4, 1984 and June 3, 1985 sampling runs during this RI). During normal operations the STP discharge contributes considerable amounts of phosphorous and phosphate to Silver Bow Creek; however, during ground-water pumping, zinc, cadmium and sulfate loads contributed by the STP are quite significant both in terms of impacts and loadings to Silver Bow Creek. Samples collected at the STP confirm significantly high concentrations of copper, iron, and zinc in the ground water around the plant. As this ground-water pumping is intermittent and irregular, it has no relationship to natural flow conditions on Silver Bow Creek, and its relative effect on water quality is variable. This source of zinc, cadmium, and sulfate could be considered a ground-water source.

3.3.1.6 PS-08A (Ranchland Discharge)

A minor discharge from the Ranchland Packing Company enters Silver Bow Creek just upstream of SS-07 (Map 1-2 Over Size). Discharge was observed twice at this site, with flows about 0.001 cfs. On December 26, 1984 the discharge had a specific conductance of 10,200 umhos/cm. No laboratory analyses were performed on this water.

Although the discharge is apparently of very poor quality, the infrequent and minor discharge suggest a negligible impact on Silver Bow Creek.

3.3.1.7 PS-11 (Silver Lake Discharge)

The Silver Lake discharge is a fairly good quality bicarbonate water with low metals concentrations, except lead. Its discharge averages about 46% of Silver Bow Creek's flow as measured at SS-11, but its metal loadings are significantly lower than those in the creek. This inflow had the effect of diluting the relatively poor quality water in Silver Bow Creek. Table 3-18 lists loads and relative impacts contributed by this discharge. Since this water is used as process water by the concentrator in Butte, operation of the concentrator affects the release of this discharge into Silver Bow Creek. The diluting effect of this discharge is removed when it is routed to the concentrator and may affect downstream water quality.

3.3.1.8 PS-10 (Stauffer Seep)

Samples from PS-10 usually were analyzed only for total phosphorus, orthophosphate, and fluoride. During the August sampling, additional parameters were analyzed and metals loadings from PS-10 proved to be insignificant. However, high concentrations of some common ions were found: sulfate at 1,020 mg/L, chloride at 130 mg/L, sodium at 124 mg/L, and calcium at 338 mg/L. Using the August discharge rate of 0.06 cfs, the sulfate load contribution represented only 3% of that in Silver Bow Creek. However, sulfate loadings may be much higher at other times. On February 26, 1985 the discharge at PS-10 was ten times greater than in August. The sulfate concentration can be estimated as about 1,000 mg/L in February, based on nearly

TABLE 3-18

LOADS CONTRIBUTED BY THE SILVER LAKE DISCHARGE (PS-11)

	LOW FLOW (Runs 11, 13, 15)		HIGH FLOW (Runs 1-3,10)	
	Load (lbs/day)	%(a)	Load (lbs/day)	%(a)
Flow	--	18.3	--	44.1
TSS	0.0	0.0	169.9	4.2
Sulfate	184	1.6	723	6.6
Cu (T)	0.6	1.4	0.3	0.6
Zn (T)	0.5	0.6	0.9	0.9
Fe (T)	1.3	0.9	11.1	5.2
As (T)	0.00	0.0	0.05	2.3
Pb (T)	0.02	0.6	0.39	18.0
Cd (T)	0.00	0.0	0.00	0.0

Note:

(a) Expressed as a percentage of measurements at the confluence with Silver Bow Creek.

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equal specific conductances for both samplings. This estimate suggests that the Stauffer seep was increasing the sulfate load of Silver Bow Creek by about 30% at the time of February sampling. Total phosphorous and orthophosphate loading by the seep, though measurable, are not significant to Silver Bow Creek. Fluoride loadings measured here cannot be compared, due to lack of fluoride data in Silver Bow Creek. However, calculations show the impact would increase fluoride concentrations in Silver Bow Creek by 0.05 mg/L at SS-11.

Potential impacts of the Stauffer seep should not be readily dismissed. The seep may be a surface expression of a greater area of contaminated ground water which eventually may reach the creek.

3.3.1.9 SS-12 (Browns Gulch)

The Browns Gulch tributary to Silver Bow Creek generally flows all year, though flows vary widely from 0.01 to 15 cfs. Loads contributed by Browns Gulch during low flows are generally minor (Table 3-19). During high flows, significant loads of TSS, iron, arsenic, and lead are contributed to Silver Bow Creek, which degrade water quality in the creek. Streambed sediments associated with the Ramsay Flats tailings deposits apparently are eroding into Browns Gulch and supplying particulate metals to Silver Bow Creek. Historical data collected on Browns Gulch above the floodplain show relatively low metals loads, hence the source is likely the Ramsay Flats tailings.

3.3.1.10 SS-15 (German Gulch)

German Gulch has good quality water with low metals concentrations. Discharge was a significant portion of Silver Bow Creek's flow as measured at SS-16, but metal loadings are quite low (Table 3-20) both in terms of loadings and impacts.

TABLE 3-19
LOADS CONTRIBUTED BY BROWNS GULCH

	LOW FLOW (Runs 11, 13)		HIGH FLOW (Runs 8,9)	
	Load (lbs/day)	%(a)	Load (lbs/day)	%(a)
Flow	--	1.2	--	21.0
TSS	8.3	0.2	4444	50.3(b)
Sulfate	11.6	0.9	2314	12.3
Cu (T)	0.1	0.4	8.3	13.3
Zn (T)	0.4	0.4	9.8	6.2
Fe (T)	0.6	0.3	229.7	33.7(b)
As (T)	0.03	0.5	2.80	42.8(b)
Pb (T)	0.01	0.3	16.94	64.9(b)
Cd (T)	0.00	0.2	0.00	0.0

Note:

(a) Expressed as a percentage of measurements at the confluence with Silver Bow Creek.

(b) Percent load contribution significantly higher than percent flow contribution, indicating degradation of SBC.

TABLE 3-20
LOADS CONTRIBUTED BY GERMAN GULCH

	LOW FLOW (Runs 1, 5, 6)		HIGH FLOW (Runs 10-12)	
	Load (lbs/day)	%(a)	Load (lbs/day)	%(a)
Flow	--	15.1	--	35.0
TSS	169.9	7.7	553.6	10.3
Sulfate	257	1.8	1252	6.4
Cu (T)	1.8	5.3	1.7	2.2
Zn (T)	0.1	0.0	1.5	0.8
Fe (T)	5.6	2.8	16.4	3.9
As (T)	0.06	2.5	0.14	3.1
Pb (T)	0.03	1.6	0.24	7.0
Cd (T)	0.00	0.0	0.00	0.0

Note:

(a) Expressed as a percentage of measurements at the confluence with Silver Bow Creek.

3.3.2 Non-Point Sources

Non-point sources are those without a well-defined entry point to Silver Bow Creek. They are generally difficult to quantify, other than to point out input areas and possible magnitude of the contribution. Two types of non-point sources are identified for this discussion: ground-water inflows and bank or bottom sediment entrainment.

3.3.2.1 Ground-Water Inflows

Areas of ground-water inflow were identified and discussed previously in the flow gains section (3.2.2):

- SS-02 to SS-03 (Metro Storm Drain);
- SS-05 to SS-06 (Silver Bow Creek at Montana Street);
- SS-06 to SS-07 (Silver Bow Creek at Colorado Tails); and
- SS-10 to SS-11 (Silver Bow Creek at Silver Bow).

Ground-water degradation of Silver Bow Creek is inferred from data collected at each surface-water station. Inflows are best measured during low-flow periods on the creek, as they have a maximum impact on those occasions. Further discussion of ground-water quality is found in Appendix B, Ground Water and Tailings Report. Impacts to Silver Bow Creek measured during the RI are described below, presented as percent contributions to the creek and gross material loadings. Changes in loadings are estimated using total constituents during low flows to minimize channel sediment effects. This procedure accounts for physical or chemical changes that may occur before the input ground water reaches a measurement station.

SS-02 to SS-03 (MSD)

During low flows, most of the water at SS-03 is derived from ground-water input, as SS-02 was dry. Therefore, a great deal of the

contaminant load also must be derived from ground water. Table 3-21 summarizes ground-water loads contributed by the MSD to Silver Bow Creek, although some of the loads may be from sediment re-entrainment in the MSD. The table shows the MSD ground water to be a significant source of zinc, cadmium, sulfate, copper, iron, arsenic, and lead to Silver Bow Creek at the confluence with Blacktail Creek. The possible origins of this metal-rich ground water are discussed in Appendix B, Ground Water and Tailings Investigation. Most, if not all, the metal loads in the MSD during base flow are from ground-water inflows, which degraded Silver Bow Creek water quality.

SS-05 to SS-06 (Montana Street)

A fairly significant ground-water inflow was present between SS-05 and SS-06 during the RI. Table 3-22 shows load increases during low flows over this stretch, after subtracting loads from Missoula Gulch.

The seepage-run data indicate the inflow to be primarily between SS-05A and SS-06. The source of this water may be alluvial ground water associated with Missoula Gulch (see Appendix B).

Large increases in copper, zinc, sulfate, arsenic, and cadmium loads are apparent in this reach. Ground-water inflow here must be of extremely poor quality to cause these drastic increases in metal loads. Average concentrations of inflow water estimated from

TABLE 3-21
AVERAGE LOAD GAINS IN THE MSD BETWEEN SS-02 and SS-03 DURING LOW FLOWS, PRESUMED TO BE PRIMARILY GROUND-WATER INPUT

	Load (lbs/day)	%(a)
Flow	--	2.0
Sulfate	1450	26.2(b)
Cu (T)	1.8	25.4(b)
Zn (T)	22.9	77.1(b)
Fe (T)	8.6	23.8(b)
As (T)	0.02	27.7(b)
Pb (T)	0.01	53.0(b)
Cd (T)	0.07	99.4(b)

Notes:

(a) Expressed as a percentage of measurements at the confluence of the MSD with Silver Bow Creek.

(b) Percent load contribution significantly higher than percent flow contribution, indicating degradation of Silver Bow Creek.

TABLE 3-22
AVERAGE LOAD GAINS ON SILVER BOW CREEK DURING LOW FLOWS

	SS-05 to SS-06		SS-06 to SS-07	
	Load (lbs/day)	%(a)	Load (lbs/day)	%(a)
Flow	--	19.4	--	7.1
Sulfate	1464	47.8(b)	899	13.7(b)
Cu (T)	7.5	379(b)	7.9	68.6(b)
Zn (T)	19.6	259(b)	39.9	125(b)
Fe (T)	4.5	29.4	14.3	40.2(b)
As (T)	0.26	44.7(b)	0.47	124(b)
Pb (T)	0.03	25.4(b)	0.01	9.0
Cd (T)	0.11	245(b)	0.10	147(b)

Notes:

(a) Expressed as a percentage of measurements at the upstream station on Silver Bow Creek.

(b) Percent load contribution significantly higher than percent flow contribution, indicating degradation of Silver Bow Creek.

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flow and load increases are listed in Table 3-23 and compared with ground water sampled north of Silver Bow Creek in the area of the Butte Reduction Works. The comparison shows that ground water enriched in metals is present in this area and is likely the source of contaminated ground water entering Silver Bow Creek in this reach.

SS-06 to SS-07 (Colorado Tailings)

Another significant ground-water inflow is present at the Colorado Tailings, although its flow contribution is half of that at Montana

TABLE 3-23
COMPARISON OF BACK-CALCULATED[a] GROUND-WATER INFLOW CONCENTRATIONS AND GROUND WATER (SS-05 to SS-06)

	SS-05 to SS-06 mg/L	Groundwater North of SBC (well DW-136) mg/L
Sulfate	160	905
Cu	0.82	43.6
Zn	2.14	162.5
Fe	0.49	0.76
As	0.03	0.0011
Pb	0.003	0.87
Cd	0.007	0.65

Note:

[a] Calculated from baseflow increases between stations as follows:

$$\text{Avg. concentration (mg/L)} = \frac{\text{Avg. load increase (lbs/day)}}{\text{Avg. flow increase (CFS)} \times (5.3944)}$$

Street. This inflow contributes significant loads of copper, zinc iron, arsenic, and cadmium to Silver Bow Creek, shown on Table 3-22. Back calculating as described on Table 3-23 yields input ground water with high concentrations of contaminants (Table 3-24).

Table 3-24 compares the average concentrations of water beneath the Colorado tailings to that entering Silver Bow Creek in this reach. The table indicates that the increased metal loads are probably derived from ground water beneath the Colorado Tailings. This interpretation is reasonable, given the large volume of tailings materials and the availability of metals to percolating waters. In

TABLE 3-24
COMPARISON OF BACK-CALCULATED[a] GROUND-WATER INFLOW CONCENTRATIONS AND GROUND WATER (SS-06 to SS-07)

	SS-06 to SS-07 mg/L	Ground Water Beneath the Colorado Tailings (MBMG well NW-2) mg/L
Sulfate	119	1847
Cu	1.05	55.6
Zn	5.28	158
Fe	1.89	220
As	0.06	0.12
Pb	0.001	0.42
Cd	0.013	0.46

Note:

[a] Calculated from baseflow increases between stations as follows:

$$\text{Avg. concentration (mg/L)} = \frac{\text{Avg. load increase (lbs/day)}}{\text{Avg. flow increase (CFS)} \times (5.3944)}$$

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addition, data from the north side of Silver Bow Creek (DW-130) show much lower metals concentrations. Some of the increased loads may also be due to ground-water inflow in the vicinity of the STP.

SS-10 to SS-11 (Silver Bow)

Although ground-water inflow can be documented in this reach by flow measurements taken in the same time frame, samples were collected on different days for all sampling runs except two (May 6 and May 20, 1985). Flows were moderate to high in these two sampling episodes, so they do not reflect ground-water input loads well. Nonetheless,

examination of these data show no significant metals load increases. Sulfate increases 20%, compared to a flow increase of 1% in this period, which could represent bank storage water being released to the creek or a contribution from the Ramsay Flats tailings.

3.3.2.2 Bank and Channel Sediment Entrainment

Bank and channel sediment entrainment is difficult to distinguish from several other phenomena that occur in Silver Bow Creek. Metals present as a solid phase are obtained by subtracting dissolved metals from total metals where this information is available (copper, zinc, and iron). However, this procedure does not distinguish between metalliferous sediments, metals adsorbed on solids, and metal precipitates.

Gains in solid-phase metals can be balanced with losses in dissolved-phase metals to account for the adsorbed and precipitated phases, thus estimating metalliferous sediment derived from the channel or bank material. In addition, lead can be used to assist in this evaluation, since lead mineral solubilities are quite low and lead generally travels as particulate material. This evaluation is a gross estimate, and only large additions between stations should be regarded as a contributions by bank or channel sediments. Because this phenomenon is most important during high flows, the snowmelt episode (March 25 - May 6) and the runoff episodes (May 29 and June 3) were used to determine contributions by this potential non-point source.

The data indicate contributions of channel or bank material during higher flows to be significant along the creek from SS-07 to SS-10 (Colorado Tailings to Silver Bow) and from SS-13 to SS-16 (Ramsay Flats to Fairmont Hot Springs). In both these reaches, increases in solid-phase metals (copper, zinc, iron, arsenic, and lead) during high flows are consistent. This probably represents previously deposited metals that are remobilized during higher flows and as such are not true "sources" of contamination. Table 3-25 summarizes metal loads contributed in both stretches where contributions were apparent. Contributions from the Colorado Tailings (SS-06 to SS-07) were not apparent during the RI. The lack of extremely high flows in Silver Bow Creek may have prevented singificant bank erosion from occurring in the study area. As mentioned in the point-source discussion, the MSD, Missoula Gulch, and Browns Gulch contribute metal-rich sediment to Silver Bow Creek during high flows as the result of erosional processes within these tributaries.

TABLE 3-25
AVERAGE LOAD GAINS ON SILVER BOW CREEK FROM BANK OR CHANNEL SOURCES DURING HIGH FLOWS

	SS-07 to SS-10		SS-13 to SS-16	
	Load (lbs/day)	% of SS-07[a]	Load (lbs/day)	% of SS-13[a]
Cu (T)	23.5	60.1	22.3	34.2
Zn (T)	25.2	28.0	26.5	17.4
Fe (T)	154.7	88.0	132.0	27.8
As (T)	2.2	94.9	2.2	42.0
Pb (T)	3.2	267.3	4.5	68.4

Note:

(a) Percent load contribution relative to upstream station (SS-07 or SS-13).

3.4 TRANSPORT OF CONTAMINANTS

The transport of metal contaminants is dependent on the processes discussed in Section 2.3.2. Analytical constraints provide a distinction only between dissolved species and solid species. Solid species (precipitated, adsorbed, or mineral sediment) were derived by subtracting dissolved metals from total metals. The actual form of the metal is predicted by solubility and equilibrium conditions and is subject to the precautions described in Section 2.3.2. This analysis could be performed only on those elements that were analyzed for both total and dissolved concentrations (iron, copper, and zinc). In many cases, other metals' behavior also can be predicted using these measurements. For example, the geochemical behavior of cadmium closely resembles that of zinc; it occurs primarily in the dissolved form and exhibits similar adsorption and precipitation tendencies. As mentioned previously, lead compounds are not soluble to any great extent, so lead transport can be predicted using solid-phase mineral sediment.

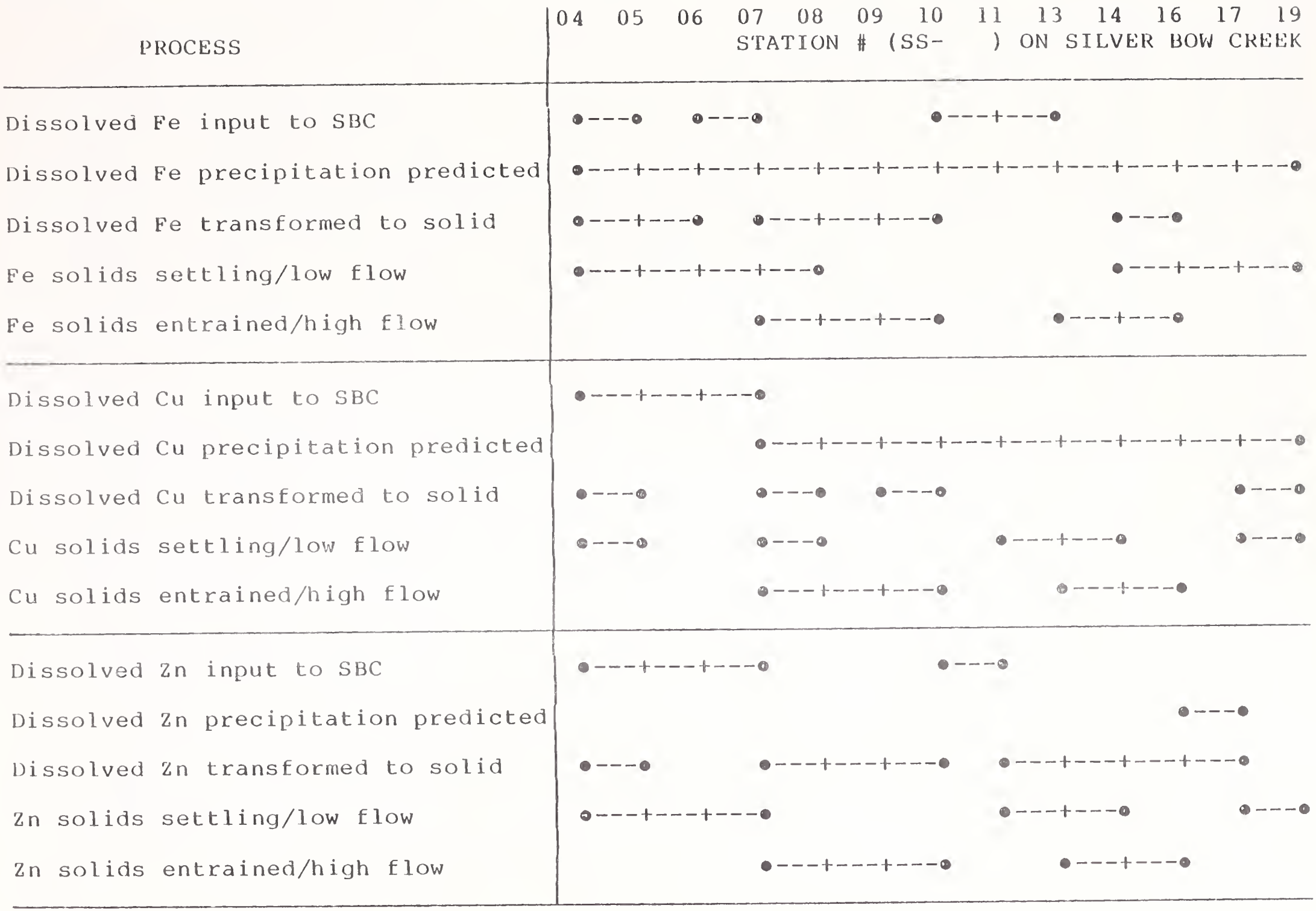
These predictions were confirmed by correlation analysis on the flow-segregated data set. In general, very good correlations are observed within two distinct sets of analytical parameters: (1) the "dissolved" suite, consisting of sulfate, zinc, dissolved copper and iron, and total cadmium, and (2) the "solid" suite, comprised of total suspended solids (TSS), "solid" copper and iron, total lead, and total arsenic.

These groupings confirm the assumption that cadmium behaves like zinc, tending to exist primarily in the dissolved phase, and lead tends to behave as a mineral sediment. Arsenic also appears to be present as a solid phase. Arsenic geochemistry is quite complex, and equilibrium calculations predict arsenic to be in a variety of dissolved phases. Adsorption to iron precipitates is an important mechanism for the removal of arsenic from solution and into the solid phase (Wagemann 1978). This is probably occurring in Silver Bow Creek.

Figure 3-4 summarizes iron, copper, and zinc behavior observed in Silver Bow Creek during this RI. Also shown are areas that thermodynamically favor precipitation of the three metals. As depicted, iron precipitation is favored everywhere in Silver Bow Creek, but as described earlier, reaction kinetics force iron precipitation to proceed slowly. Copper precipitation is favored downstream from Station SS-07 (Colorado Tailings) due to increases in pH and alkalinity. Zinc precipitation is not predicted anywhere except between SS-16 and SS-17 (Fairmont Hot Springs to Opportunity), where precipitation is possible but not heavily favored.

During lower flows, dissolved metals enter Silver Bow Creek from the MSD and ground water. The higher-pH receiving waters accelerate iron precipitation, and zinc and copper are transformed to solid phases but not precipitated. They are most likely adsorbed to the iron precipitates and may be co-precipitated. These solid

FIGURE 3-4
SUMMARY OF TRANSPORT MECHANISMS PREDICTED AND OBSERVED DURING THE SBC RI


PROCESS
04 05 06 07 08 09 10 11 13 14 16 17 19
STATION # (SS-) ON SILVER BOW CREEK
Dissolved Fe input to SBC
Dissolved Fe precipitation predicted
Dissolved Fe transformed to solid
Fe solids settling/low flow
Fe solids entrained/high flow
Dissolved Cu input to SBC
Dissolved Cu precipitation predicted
Dissolved Cu transformed to solid
Cu solids settling/low flow
Cu solids entrained/high flow
Dissolved Zn input to SBC
Dissolved Zn precipitation predicted
Dissolved Zn transformed to solid
Zn solids settling/low flow
Zn solids entrained/high flow

phases then settle to the creek bottom and are remobilized during higher flows, transported as mineral sediments or adsorbates.

Settling during low flows is observed between Stations SS-04 (Blacktail Creek at mouth) and SS-08 (Rocker) and also between SS-11 (Ramsay Flats) and SS-19 (Upper pH shack). These areas of Silver Bow Creek have a lower gradient and are natural stretches for fluvial deposition of solids. However, higher flows will remobilize these solids further downstream. During lower flows, dissolved constituents comprise 15-50% of the total copper, 14-100% of total zinc, and only 1-10% of the total iron being transported in Silver Bow Creek (Table 3-26). Table 3-26 also demonstrates the conversion of copper, zinc, and iron from dissolved to solid forms as they travel down Silver Bow Creek. High flows are responsible for transporting two to ten times higher total metal loads than low flows. Most of this occurs as solids transport, both as mineral sediment and as remobilization of previously deposited solids (adsorbates and precipitates). Several sources become important at higher flows; the MSD, Missoula Gulch, and Browns Gulch contribute significant loads of metals in the solid phase. Loading data is summarized in Table 3-27 for both high and low flows. Comparison of these data demonstrate how significant high flows are to the transport of metals in Silver Bow Creek. Though high flow events are few, especially during this RI, the amount of metals transported by the creek during high flows far exceed those carried during baseflows.

TABLE 3-26
PERCENTAGE OF TOTAL COPPER, ZINC, AND IRON IN DISSOLVED FORM DURING HIGH AND LOW FLOWS

Station[a]	HIGH FLOWS			LOW FLOWS		
	Cu	Zn	Fe	Cu	Zn	Fe
SS-03 T	45.6	100.0	43.9	38.5	83.0	44.5
SS-04	32.6	39.5	9.4	31.1	49.9	7.3
SS-05	40.5	75.3	9.4	26.5	92.6	8.3
PS-04 T	19.7	26.4	0.2	40.9	95.4	4.3
SS-06	41.3	90.3	10.5	42.4	99.6	3.5
PS-08 T	66.5	100.0	35.3	37.2	89.2	19.0
SS-07	52.3	100.0	14.2	51.3	100.0	25.5
SS-08	37.2	89.7	6.9	30.8	71.2	5.6
SS-09	35.2	86.6	4.9	33.8	51.8	6.5
SS-10	30.5	74.9	5.0	15.2	34.4	0.8
PS-11 T	82.4	50.9	16.0	33.3	29.4	25.7
SS-11	31.0	49.6	12.8	27.5	65.7	3.8
SS-12 T	17.3	20.7	3.8	32.8	100.0	7.5
SS-13	30.4	66.7	4.0	36.0	54.4	7.9
SS-14	29.3	64.6	3.0	29.5	29.1	4.6
SS-15 T	69.9	46.6	19.2	28.2	61.8	24.1
SS-16	27.7	47.3	1.5	30.6	13.7	3.3
SS-17	21.9	41.3	2.4	26.3	13.9	4.3
SS-19	26.4	52.0	5.1	35.3	13.9	4.3

Note:

(a) T = Tributary inputs to Silver Bow Creek.

TABLE 3-27
AVERAGE LOADS (in lbs/day) MEASURED ON SBC DURING THE RI (LOW FLOW)[a]

	Flow	TSS	Cu-Diss.	Cu-Total	Zn-Diss.	Zn-Total	Fe-Diss.	Fe-Total	As Total	Pb Total
SS-04 Blacktail Creek	9.7	228	0.5	1.5	1.1	2.2	1.9	26.4	0.3	0.2
SS-03 (T) Metro Drain	0.3	39	0.7	1.8	15.8	18.0	4.8	10.7	0.0	0.1
SS-05 Silver Bow Creek	9.7	445	0.5	1.7	9.3	10.0	3.0	36.0	0.3	0.2
PS-04 (T) Missoula Gulch	0.1	6	0.0	0.0	0.4	0.4	0.0	0.2	0.0	0.0
SS-06 Silver Bow Creek	11.2	360	4.2	9.8	29.3	29.5	1.4	39.9	0.6	0.3
PS-08 (T) Sewage Plant[b]	8.6	539	0.7	1.9	3.8	4.2	1.8	9.4	0.2	0.6
SS-07 Silver Bow Creek	20.8	719	10.2	19.9	77.5	75.7	15.8	62.1	0.8	0.6
SS-08 Silver Bow Creek	20.5	1088	6.2	20.3	51.6	72.5	6.1	108.8	1.0	0.9
SS-09 Silver Bow Creek	20.4	1201	8.3	24.6	36.9	71.2	7.8	120.8	1.4	1.0
SS-10 Silver Bow Creek	20.9	2192	6.4	42.4	31.3	91.1	2.2	283.2	1.9	2.7
PS-11 (T) Silver Lake Dis.	5.5	88	0.2	0.7	0.1	0.5	0.5	1.9	0.0	0.0
PS-10 (T) Stauffer Seep	0.1	--	--	--	--	--	--	--	--	--
SS-11 Silver Bow Creek	28.7	1020	7.3	26.5	62.0	94.4	5.3	140.2	1.7	1.4
SS-12 (T) Browns Gulch	0.3	9	0.1	0.4	1.0	0.9	0.0	0.4	0.0	0.0
SS-13 Silver Bow Creek	26.2	731	8.0	22.3	47.0	86.3	8.7	110.2	1.1	0.8
SS-14 Silver Bow Creek	26.3	1171	6.9	23.5	22.2	76.4	4.9	107.0	1.2	0.6
SS-15 (T) German Gulch	3.8	96	0.2	0.6	0.1	0.2	0.5	2.0	0.1	0.1
SS-16 Silver Bow Creek	29.8	1478	7.3	23.8	9.5	69.6	3.3	99.9	3.2	1.0
SS-17 Silver Bow Creek	27.9	1253	6.2	23.7	9.5	683.	3.9	90.1	1.2	0.6
SS-19 Silver Bow Creek	34.3	1317	8.1	22.9	9.2	65.7	7.1	163.1	2.0	0.9

Notes:

(a) T indicates tributary input to Silver Bow Creek.
(b) STP high flows are when ground water is being pumped; low flows are all other times.

TABLE 3-27
AVERAGE LOADS (in lbs/day) MEASURED ON SBC DURING THE RI (HIGH FLOW)(Continued)[a]

	Flow	TSS	Cu-Diss.	Cu-Total	Zn-Diss.	Zn-Total	Fe-Diss.	Fe-Total	As Total	Pb Total
SS-04 Blacktail Creek	23.4	1892	2.6	8.0	3.8	9.6	20.3	217.1	1.0	0.8
SS-03 (T) Metro Drain	0.9	128	2.2	4.8	44.9	40.3	13.9	31.7	0.1	0.1
SS-05 Silver Bow Creek	22.9	1915	2.7	6.6	22.5	29.9	17.8	189.1	1.1	2.8
PS-04 (T) Missoula Gulch	0.5	606	0.3	1.6	1.7	6.3	0.1	39.4	0.1	0.4
SS-06 Silver Bow Creek	25.8	2565	10.2	24.8	49.8	55.1	21.1	201.0	1.6	1.3
PS-08 (T) Sewage Plant[b]	12.1	953	3.9	5.9	284.2	279.9	3.2	9.0	0.3	0.3
SS-07 Silver Bow Creek	36.2	3406	19.2	36.8	168.5	164.8	25.1	276.2	2.1	1.2
SS-08 Silver Bow Creek	35.5	3231	17.2	46.4	143.6	160.1	19.3	278.0	3.2	2.8
SS-09 Silver Bow Creek	37.2	3904	20.0	56.9	143.4	165.6	14.9	306.8	3.0	2.5
SS-10 Silver Bow Creek	36.9	4734	18.4	60.4	129.6	172.9	16.6	331.2	4.3	4.4
PS-11 (T) Silver Lake Dis.	19.9	354	1.1	1.3	0.7	1.3	1.9	12.0	0.3	0.5
PS-10 (T) Stauffer Seep	0.7	--	--	--	--	--	--	--	--	--
SS-11 Silver Bow Creek	48.0	3798	17. 7	57.2	134.3	271.0	53.8	419.1	5.5	7.6
SS-12 (T) Browns Gulch	13.3	4444	1.4	8.3	2.0	9.8	8.8	229.7	2.8	16.9
SS-13 Silver Bow Creek	60.8	6524	21.1	69.4	143.5	215.3	19.5	491.6	6.3	9.3
SS-14 Silver Bow Creek	61.3	8195	23.9	81.4	151.4	234.2	17.7	585.4	6.2	7.1
SS-15 (T) German Gulch	27.4	724	1.5	2.1	0.7	1.5	3.1	16.4	0.3	0.3
SS-16 Silver Bow Creek	83.0	8515	25.8	93.3	100.8	212.9	9.3	640.3	7.2	7.3
SS-17 Silver Bow Creek	88.8	10822	21.3	97.5	98.2	238.0	16.9	704.2	9.6	7.5
SS-19 Silver Bow Creek	101.4	11639	25.6	97.2	120.9	232.4	36.1	704.6	16.2	8.5

Notes:

(a) T indicates tributary input to Silver Bow Creek.
(b) STP high flows are when ground water is being pumped; low flows are all other times.

3.5 CONTAMINANT FATE

Contaminants leaving the Silver Bow Creek System move into either the Warm Springs Ponds (WSP) or the upper Clark Fork River. Although precipitation and settling do occur along Silver Bow Creek, high flows remobilize these deposits so the ultimate fate of contaminants in Silver Bow Creek is one of these two surface water bodies. Normally, all Silver Bow Creek water is routed to the Warm Springs Pond system, where it is treated at high pH and allowed to settle. Not all the metal loads are removed, however. Some of the metals leave the pond system via the Pond 2 outlet (PS-12). During very high flows, the treatment system is bypassed, and untreated Silver Bow Creek water flows directly to the Mill-Willow bypass and then to the upper Clark Fork. These high flows are responsible for the majority of metal loads transported in Silver Bow Creek. By comparing all input and outlet metal loads, a rough estimate of metals remaining in the pond system can be made (Appendix C, Warm Springs Ponds). Those metals leaving the ponds then have a fate somewhere downstream in the Clark Fork, with their ultimate fate controlled by natural fluvial processes or man-made impoundments. The data are segregated to reflect high- and low-flow conditions, since the performance of the pond system varies widely with flow.

3.5.1 Warm Springs Ponds

Table 3-28 lists total contaminant loads removed by the Warm Springs Ponds, both in pounds per day and as a percentage of incoming loads

TABLE 3-28
TOTAL LOADS REMOVED BY THE WARM SPRINGS POND SYSTEM[a]

	HIGH FLOWS (Runs 8, 9, 10, 12)		LOW FLOWS (runs 13, 14, 15)	
	LOAD (LBS/DAY)	% REMOVED[b]	LOAD (LBS/DAY)	% REMOVED[b]
TSS	8082	59.1	967	68.8
Sulfate	-8293	-15.4	5673	21.9
Cu	54.3	57.6	20.5	88.0
Zn	150.9	64.1	64.6	95.0
Fe	366.6	52.6	149.8	85.9
As	8.3	47.6	1.1	39.3
Pb	9.6	94.8	0.8	81.3
Cd	0.5	69.5	0.1	91.8

(a) Calculated by comparing all input and output loads.

(b) Percentage of input loads removed, remaining in the Ponds.

for high and low flows. Appendix C, Warm Springs Ponds Investigation, thoroughly discusses the Warm Springs Ponds operation during the RI Period. Table 3-28 shows low removals for copper, zinc, iron, arsenic, and sulfate during high flows. During lower flows, which occur most of the year, removal rates are quite high, except for arsenic and sulfate. Despite the contaminants that are discharged to the Clark Fork River, a significant amount are deposited in the Warm Springs Pond system. Their ultimate fate is probably pond sediments, even though some metals may be remobilized during high flows or pond upsets, or may travel into the ground-water system.

3.5.2 The Upper Clark Fork River

The other major receptor for contaminants delivered by Silver Bow Creek is the Clark Fork River. Two major routes are possible: (1) metals that travel through or are remobilized from the pond system or (2) those that bypass the ponds during high flows. Table 3-29 lists the three major inputs that form the Clark Fork River and loads contributed by each. During low flows, the Pond 2 outfall (PS-12) contributes slightly more sulfate and arsenic, the Mill-Willow Bypass (SS-25) adds significant dissolved iron and cadmium, and Warm Springs Creek supplies the largest amount of TSS, total copper and iron, dissolved zinc, and lead. Higher flows significantly increase the amount of sulfate, total copper and iron, total and dissolved zinc, and lead leaving the ponds and entering the Clark Fork River, while increased dissolved iron and arsenic are

TABLE 3-29
FLOWS (CFS) AND LOADS (LBS/DAY) CONTRIBUTED TO THE
UPPER CLARK FORK RIVER FROM MAJOR INPUTS

	LOW FLOWS			HIGH FLOWS		
	WARM SPRINGS PONDS PS-12	MILL WILLOW BYPASS SS-25	WARM SPRINGS CREEK SS-28	WARM SPRINGS PONDS PS-12	MILL WILLOW BYPASS[a] SS-25	WARM SPRINGS CREEK SS-28
Flow	15.6	17.3	47.9	114.4	77.6	106.7
TSS	315	454	1390	3308	3074	18906
Sulfate	11544	20439	28344	69124	23686	39303
Cu (T)	1.6	3.0	14.4	40.6	18.9	38.4
Zn (T)	2.5	6.6	1.0	84.0	15.9	18.0
Fe (T)	11.5	45.1	52.3	322.5	220.8	611.1
As	0.8	1.4	1.5	7.4	18.5	2.0
Pb	0.1	0.2	0.8	4.9	0.7	2.9
Cd	0.0	0.0	0.0	0.1	0.0	0.0

Note:

(a) Does not include bypass of ponds.

entering from the Bypass. The effect of bypassing the Warm Springs Ponds on the discharge to the Clark Fork is probably significant. No data was collected during a flow bypass, but other data suggest large amounts of metals are released to the Clark Fork River. The primary effect of the Warm Springs Ponds is to remove solid phase metals from Silver Bow Creek; hence, when they are bypassed, a large but unmeasured amount of solid (suspended) contaminants enter the upper Clark Fork River.

Data collected during this RI further downstream in the Clark Fork are sparse. Two runs (11 and 13) were sampled down to Garrison (SS-36) and analyzed for total metals (copper, zinc and iron) only. Run 11 was performed during a relatively high flow period on the Clark Fork, while run 13 was done during low flow and may have included many irrigation withdrawals and returns.

While considering those limitations, total metals tended to increase between SS-29 (Perkins Lane Bridge) and SS-33 (Railroad Bridge, north of Deer Lodge) during high flow (Run 11). This may have been due to mobilization of bank or channel sediments from the extensive tailings/sediment deposits along the Clark Fork in this area. This increase in metal loads also may have been due to the inflow of several tributary creeks to the Clark Fork. One of these, Cottonwood Creek, drained the Emery-Zosell mining district, which may be a source of metals to the river. Low flow (Run 13) showed very few trends, perhaps indicating that no prominent metal sources (both point and non-point) exist under this flow condition.

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4.0 CONCLUSIONS

This chapter reviews the sources, transport, and fate of metal contaminants observed during the Silver Bow Creek (SBC) Remedial Investigation (RI). The severity and extent of contamination also is presented. Conclusions are based primarily data collected during this RI (December 1984-August 1985) and not on historic data. The chapter ends with recommendations for additional data collection.

Conclusions for this RI are based on data collected during a nine-month period of drier-than-average weather, as shown in precipitation and snowpack records and flows in Silver Bow Creek. The effects of a dry year are fewer surface runoff events and fewer high-flow events that cause sediment erosion and transport. These events, while more frequent in normal years, were quantified during this RI and can be used to predict effects in normal or wet years. The lower flows created an opportunity to study ground-water inflows to Silver Bow Creek. Temporal trends in flow data allowed the segregation of data into high and low flow regimes, which permitted more detailed analysis of the major mechanisms at work in the study area.

The major surface sources of flow to Silver Bow Creek were the Butte STP (PS-08) and the Silver Lake Discharge (PS-11); Browns Gulch (SS-12) and German Gulch (SS-15) added significant amounts of water during high-flow periods. The MSD (SS-03) and Missoula Gulch (PS-04) generally contributed less than 5% of the flow in Silver

Bow Creek. Significant ground-water inflows were identified in the MSD (SS-02 to SS-03) and between Montana Street and the western end of the Colorado Tailings (SS-05 to SS-07). Each of these sources of water were evaluated as sources of contaminants.

4.1 SOURCES

Contaminants enter the Silver Bow Creek system through two major pathways: surface runoff and ground-water inflow. An additional pathway is the re-entrainment of previously deposited bank and channel materials. Distinguishing these pathways is important so that appropriate remedial alternatives can be developed during the feasibility study. The surface-water data identifies major contaminant sources throughout the Silver Bow Creek study area. The most dramatic increases in contaminants occur in and near Butte, and sources generally become less important as the creek approaches the Warm Springs Ponds.

Table 4-1 summarizes contaminant loads contributed by each source during the entire RI period. The amount of contaminants contributed by each source varies considerably with flow conditions. While it appears that the MSD and Missoula Gulch contribute relatively small loads when compared to Browns Gulch, their relative impact in terms of water quality degradation may be greater. Two factors must be carefully evaluated together in planning remedial options: (1) total material loadings to the creek, and (2) relative impact of each point source on water quality in Silver Bow Creek.

Table 4-1
FLOWS AND LOADS CONTRIBUTED BY POINT SOURCE TO SILVER BOW CREEK OVER THE ENTIRE RI PERIOD (DEC. 1984 - AUG. 1985).

	Metro Storm Drain (SS-03)	Missoula Gulch (PS-04)	Butte Sewage Treatment Plant (PS-08)		Silver Lake Discharge (PS-11)	Browns Gulch (SS-12)	German Gulch (SS-15)
			Entire RI	Normal[a]			
Flow ($10^6 ft^3$)	12.7	2.6	228.4	221.4	324.5	70.4	258.2
Sulfate (lbs.)	478000[b]	17000[b]	804000	679000	168000	153000	149000
Cu (lbs.)	551[b]	94[b]	681	539	268	341	232
Zn (lbs.)	6664[b]	415[b]	11473[b]	1313	229	729	211
Fe (lbs.)	4411[b]	1908[b]	2429	2399	1660	8603[b]	2114
As (lbs.)	12.9[b]	5.3[b]	58.1	54.8	3.0	132.0[b]	46.
Pb (lbs.)	13.9[b]	23.9[b]	43.4	41.9	83.0	549.1[b]	16.
Cd (lbs.)	25.5[b]	1.7[b]	24.4[b]	0.4	0.0	0.3	0.0

Notes:

(a) During normal operations, excludes ground-water pumping episodes (corrected to entire RI period).

(b) Degrades Silver Bow Creek Water Quality at confluence.

Table 4-1 shows the MSD and Missoula Gulch are the primary point sources causing degradation of Silver Bow Creek. At higher flows, Browns Gulch becomes an additional degradational point source of iron, arsenic, and lead; the actual source is likely the Ramsay Flats tailings deposit. When the STP is pumping ground water, it also degrades Silver Bow Creek with zinc and cadmium.

Non-point source contributions are presented in Table 4-2 for comparison with Table 4-1. The ground-water inputs shown are extrapolated from low-flow conditions; high-flow inputs are assumed to be similar. The comparison shows that ground water entering the creek between SS-05 (Montana Street) and SS-07 (Colorado Tailings) is a major source of copper, zinc, arsenic, cadmium, and sulfate. Previously deposited channel or bank sediments appear to be mobilized during higher flows (see Table 4-2), though flows were probably not high enough to cause significant bank erosion during this RI. Though the data are not conclusive, bank entrainment and/or channel sediment re-entrainment appear to be major "sources" of copper, iron, arsenic, and lead to Silver Bow Creek. Channel sediment re-entrainment should not be considered a source, while bank erosion should be, and distinguishing the two is not possible with RI data.

Table 4-3 summarizes and ranks the contaminant sources outlined above during this remedial investigation of Silver Bow Creek. The ranking in Table 4-3 is based on total loads delivered to Silver Bow Creek during the RI, not on water quality degradation effects. Those effects must be evaluated independently. Tables 4-1, 4-2,

TABLE 4-2
FLOWS AND LOADS CONTRIBUTED BY NON-POINT SOURCES
TO SILVER BOW CREEK OVER THE ENTIRE RI PERIOD

	GROUND WATER			BANK OR CHANNEL SEDIMENT ENTRAINMENT[a]	
	SS-02 to SS-03 (MSD)	SS-05 to SS-06 (GW1)	SS-06 to SS-07 (GW2)	SS-07 to SS-10 (SED1)	SS-13 to SS-16 (SED2)
Flow ($10^6 ft^3$)	9.1	30.2	26.9	--	--
Sulfate (lbs.)	376000	401000	246000	--	--
Cu (lbs.)	412	2551	2452	1645	1561
Zn (lbs.)	5870	5428	12188	1764	1855
Fe (lbs.)	2570	0	5036	10829	9240
As (lbs.)	7.1	63.4	139.2	154	154
Pb (lbs.)	3.1	11.7	16.6	224	315
Cd (lbs.)	15.4	17.0	27.9	--	--

Note:

(a) Probably channel sediment re-entrainment deposited from another source.

TABLE 4-3
RANKING OF CONTAMINANT LOADING SOURCES TO SILVER BOW CREEK
USING TOTAL LOADS DELIVERED DURING THE ENTIRE RI PERIOD[a]

	1	2	3	4	5
Cu	GW1	GW2	SED1[d]	SED2[d]	PS-08[b]
Zn	GW2	PS-08[b]	SS-03	GW1	SED2[d]
Fe	SED1[d]	SED2[d]	SS-12	GW2	SS-03
As	SED1[d]	SED2[d]	GW2	SS-12	GW1
Pb	SS-12	SED2[d]	SED1[d]	PS-11	PS-08[c]
Cd	GW2	SS-03	PS-08[b]	GW1	--
Sulfate	PS-08[c]	SS-03	GW1	GW2	PS-11

NOTES:

(a) Key:

GW1 = Groundwater inflow between SS-05 and SS-06
GW2 = Groundwater inflow between SS-06 and SS-07
SS-03 = Metro Storm Drain
PS-04 = Missoula Gulch
PS-08 = Butte Sewage Treatment Plant
PS-11 = Silver Lake Discharge
SS-12 = Browns Gulch
SED1[d] = Sediment Entrainment between SS-07 and SS-10
SED2[d] = Sediment Entrainment between SS-13 and SS-16

(b) PS-08 (STP) during entire study, including ground-water pumping.

(c) PS-08 (STP) during normal operations, not including ground-water pumping.

(d) Probably channel sediment re-entrainment, deposited from another source.

and 4-3 may be used to extrapolate the 1985 RI data to normal or wet years.

4.2 TRANSPORT

Analysis of the RI data indicate that most metal contaminants (iron, copper, lead, and arsenic) are transported as solid phases, either as mineral sediments, precipitates, or adsorbates. Zinc and cadmium are transported primarily as dissolved constituents, although some are bound as adsorbates.

Conditions in Silver Bow Creek favor the precipitation of iron along the entire creek. Precipitation of copper is favored downstream of station SS-07, and zinc should not precipitate anywhere except very near the Warm Springs Ponds. Iron precipitation is slow (kinetically controlled), hence more is found in a dissolved state than predicted by equilibrium calculations. Copper and arsenic adsorb to, and may be coprecipitated with, iron. Lead is generally not soluble and is present primarily as mineral sediment. Zinc and cadmium are present primarily in dissolved forms. Zinc is more likely to adsorb than cadmium under conditions found in Silver Bow Creek.

Contaminant transport is most significant during the relatively few high-flow events, where solid phases are mobilized. Bedload sediment transport, though not measured, is probably significant in the movement of solid-phase contaminants in Silver Bow Creek.

4.3 FATE

Contaminants delivered by Silver Bow Creek have two possible fates: the Warm Springs Treatment Ponds and the Clark Fork River. Table 4-4 presents total amounts of contaminants that remained in the Warm Springs Ponds or that were supplied to the Clark Fork River during the RI. Using the entire study period integrates contaminant loads for the relatively infrequent high-flow events, the normal low-flow conditions, and accounts for the lower pond system efficiencies in winter. As noted earlier, 1985 was a low-water year, and an average year would probably increase the amount of contaminants delivered to both receptors. Because the ponds are less efficient during higher flows, a relatively greater amount would be delivered to the Clark Fork River. The table shows the pond system removed approximately 87% of the cadmium, 73% of the zinc and lead, 65% of the copper, 60% of the iron and zinc, and 36% of the arsenic loads delivered by Silver Bow Creek during the RI period. The unremoved contaminants then flow into the upper Clark Fork River, where their ultimate fate is determined primarily by impoundments (dams) and natural fluvial processes. The implication is that, except for low flows during the summer, approximately 40% of the contaminants delivered to the Warm Springs Ponds are not removed and continue into the Clark Fork River.

TABLE 4-4
FATE OF CONTAMINANTS DELIVERED BY SILVER BOW CREEK DURING THE RI PERIOD[a]

	Amount Remaining in Warm Springs Ponds		Amount Released by Warm Springs Ponds to the Clark Fork River[b]	
	(lbs)	% of input	(lbs)	% of input
Sulfate	-232,111	-3.3	7,265,778	103.3
Cu	8,531	65.0	4,594	35.0
Zn	22,428	60.4	14,704	39.6
Fe	52,586	59.9	35,204	40.1
As	674	36.3	1,183	63.7
Pb	681	72.8	254	27.2
Cd	93	87.0	14	13.0

Notes:

(a) Includes only the period December 26 to August 27, 1985 (Runs 2-15). Inlet (SS-19) was frozen from December 3, 1984 through March 11, 1985 sampling runs. Data from SS-16 was used for these periods.

(b) Does not include Pond System bypass of early June 1985.

4.4 SEVERITY AND EXTENT OF CONTAMINATION

This RI found definite evidence of surface-water contamination in Silver Bow Creek and found some evidence of water quality problems on the upper Clark Fork River. This contamination indicates a severely degraded resource and may pose hazards to human health, as well as to aquatic life and the environment.

The contamination is both severe and extensive, as shown in Table 4-5. The table shows the MSD (SS-02 and SS-03) to be the most severely contaminated part of the study area. Concentrations of

TABLE 4-5
EXCEEDENCES OF USEPA CRITERIA
DURING THE SBC RI

	Exceeding EPA Drinking Water Criteria for Total Metals (USEPA 1976)						n	Exceeding EPA 1-hour Aquatic Life Criteria Criteria (USEPA 1985a-d, USEPA 1986)				
								Dissolved		Total		
	Cu	Zn	Fe[a]	As	Pb	Cd		Cu	Zn	As[b]	Pb	Cd
Criteria mg/l	1.0	5.0	0.3	0.05	0.05	0.01		(c)	(c)	0.04		
SS-02 Upper MSD	2	2	5		1	2	6	5	6	1		2
SS-03 Lower MSD	4	14	14	1	2	12	16	14	14	1	1	2
SS-04 Blacktail Creek			13		1		15	3			1	
SS-05 SBC @ Montana Street			14		1		15	2	13			
PS-04 Missoula Gulch			7	1	5	2	9	8	8	1	2	
SS-06 SBC above Colo. Tails			14				15	4	14			
PS-08 STP	1	2	3			1	15	4	6			
SS-07 SBC below Colo. Tails	1		15	1	3	1	16	5	15	1	2	1
SS-08 SBC @ Rocker			15		1		15	4	14			
SS-09 SBC @ Nissler			14				15	14	13			
SS-10 SBC @ Silver Bow			14		1		15	14	13			
PS-11 Silver Lake Dis.							15	1				
SS-11 SBC @ Ramsay			14	1	1		15	14	14	1		
SS-12 Browns Gulch	1	2	10	1	2	1	14	7	5	2	1	1
SS-13 SBC @ Dawson			14		1	1	15	14	13			1
SS-14 SBC @ Miles Crossing			14		1		15	14	12			
SS-15 German Gulch							15	1				
SS-16 SBC @ Fairmont			14		3		15	13	11		2	
SS-17 SBC @ Opportunity			10				11	10	6			
SS-19 SBC @ Pond inlet			11				11	11	6	1		
PS-12 Pond 2 Discharge			9				17	4	4			
SS-29 Clark Fork River			10				15	1				

(a) Secondary Drinking Water Criteria (USEPA 1976)
(b) Aquatic Life effects (USEPA 1980)
(c) Standard depends on hardness value.

total cadmium and zinc regularly exceed drinking water standards, and other contaminants are less frequently above this standard. Missoula Gulch is also regularly above the standard for lead, and infrequently for other metals.

Aquatic Life Criteria (1-hour) for copper and zinc (USEPA 1985c and USEPA 1986) are regularly exceeded at most sites along Silver Bow Creek, indicating the contamination extends downstream to the Warm Springs Ponds. This is a conservative comparison, since USEPA recommends using "acid-soluble" concentrations and only dissolved concentrations were used in this study, thereby underestimating the acid-soluble metals.

During the storm event of May 29, 1985 all the measured total metals (arsenic, cadmium, copper, iron, lead, and zinc) exceeded Federal drinking water standards at most of the Silver Bow Creek stations measured. This event demonstrates both that the severity and the extent of surface water contamination greatly increases during storm runoff conditions.

Another parameter of concern on Silver Bow Creek is pentachlorophenol (PCP), which was detected at SS-06 just below the Montana Pole and Treatment site. The concentration once exceeded the drinking water lifetime health advisory for adults of 0.22 mg/L. The Montana Pole and Treatment site is currently being handled by a USEPA emergency response team.

4.5 RECOMMENDATIONS

This section recommends additional data collection that may be necessary for the completion of the feasibility study on Silver Bow Creek. Justification for each of the data needs is also provided.

Additional data is needed in four areas:

(1) Identification of ultimate sources of contamination to Silver Bow Creek;

(2) Effect of high flows and storm runoff on the floodplain tailings along Silver Bow Creek;

(3) Continued monitoring of flow on SBC; and

(4) Additional characterization of the upper Clark Fork River.

4.5.1 Identification Of Ultimate Sources Of Contamination

To determine the ultimate source of metals found in Silver Bow Creek, contaminant sources outside the current RI study area must be measured and compared. This sampling should include mines and tailings deposits in Butte and the surrounding areas. Inputs to the storm sewers need to be identified and quantified.

4.5.2 Effect Of High Flows and Storm Runoff On Floodplain Tailings Deposits

Data collected to date are inconclusive about the effects of high flow and storm events on fluvially deposited tailings which form some of the Silver Bow Creek flood plain. The effect of very high flows

on stream bank stability and erosion needs a more detailed evaluation as a possible source of metals to Silver Bow Creek during those events. Storm events cause erosion and transport of the surface of the deposits to Silver Bow Creek. This surface runoff may be a source of contamination and should be quantified to determine its significance.

A sampling episode is necessary during one or more high flow and storm events, preferably around the Ramsay Flats and Colorado Tailings areas. This episode should involve sampling above, along, and below the tailings deposits as well as runoff from the surface. A means to measure bank erosion also should be employed.

4.5.3 Continued Monitoring of Flow on Silver Bow Creek

During the RI, continuous flow data were obtained from four sites along Silver Bow Creek. These data, in conjunction with the USGS gage data below Colorado Tailings, provided the means of assessing the temporal variation in flow. Because the flow regime measured was below normal, the usefulness of these data for estimating the design and operation of possible remedial alternatives is limited. The four continuous recording gages established during the Silver Bow Creek RI should be reactivated at least during the spring, summer, and fall seasons of another year. The data then collected can be used to extrapolate RI data to normal or wet years.

4.5.4 Additional Sampling on the Upper Clark Fork

The very limited sampling along this portion of the study area was insufficient to provide a meaningful characterization. If this area is important to the overall RI/FS goals, additional data are necessary to characterize bank sediment entrainment and ground-water inflow as sources of contaminants to the Clark Fork River.

DRAFT

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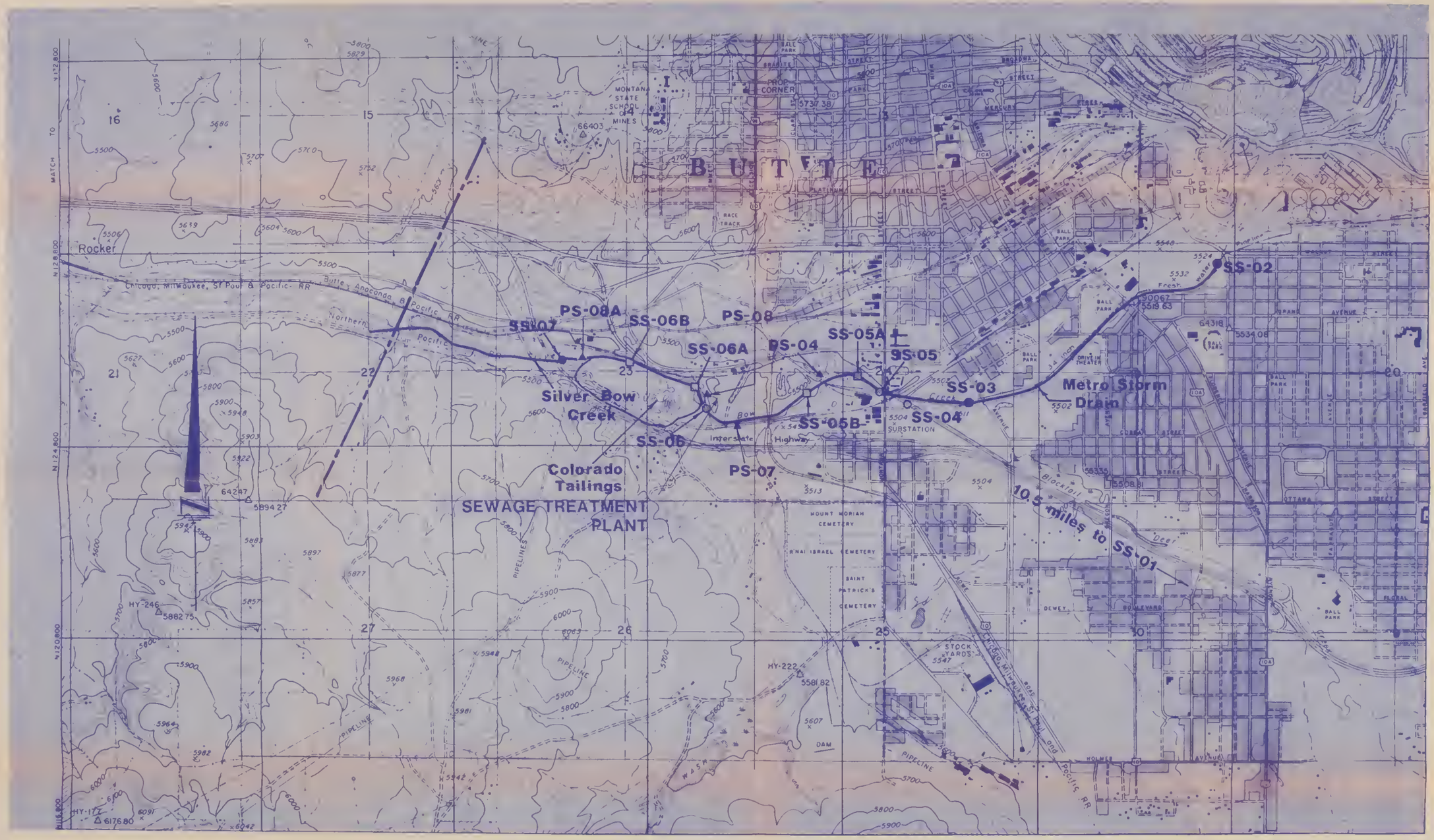


LEGEND

- ○ SURFACE WATER SAMPLE SITE
- ● PERMANENT GAGE SITE AND SURFACE WATER SAMPLE SITE
- ▲ POINT SOURCE SAMPLE SITE
- □ SEEPAGE SURFACE WATER SAMPLE SITE

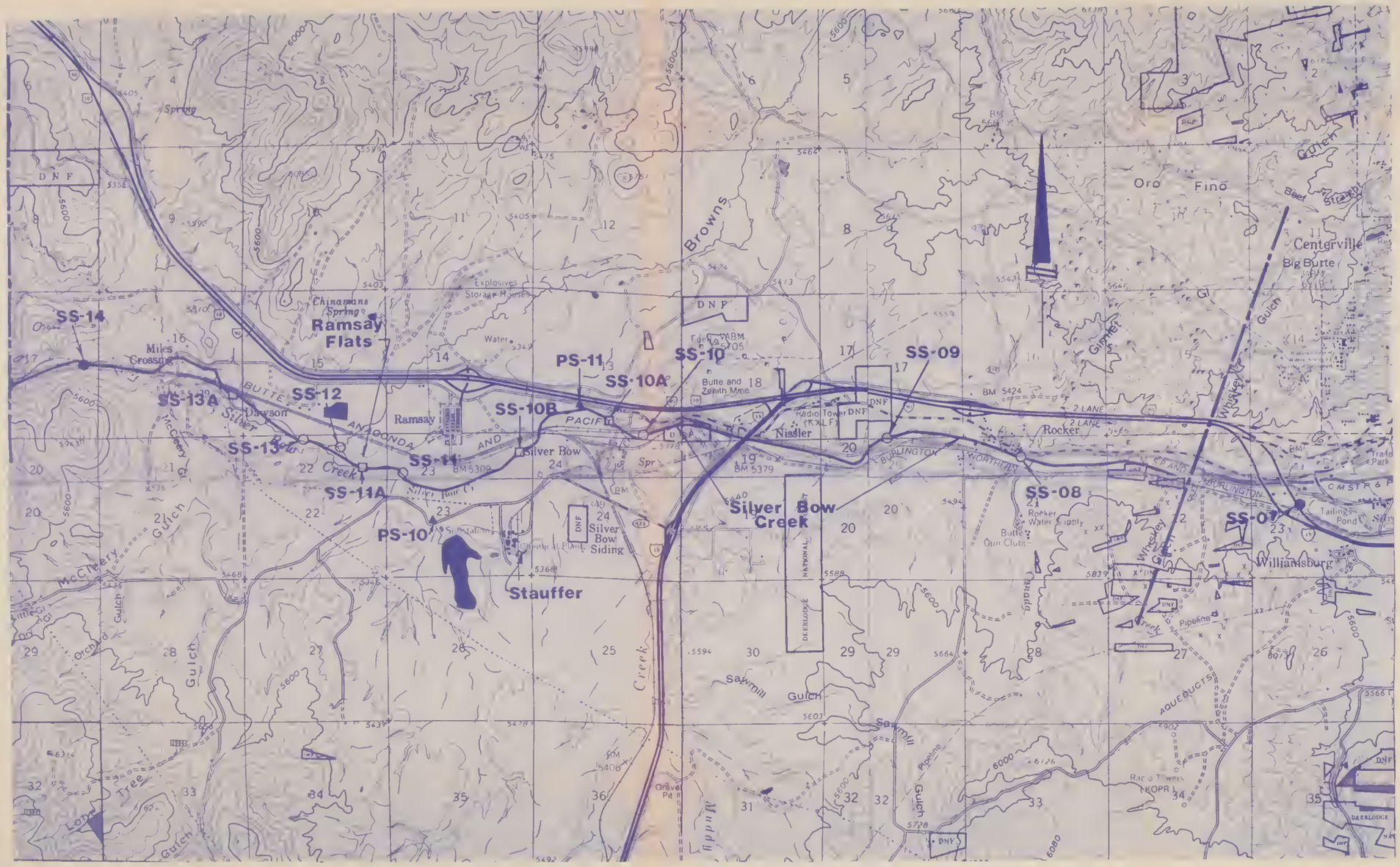
0 1000 2000'

SILVER BOW CREEK

REMEDIAL INVESTIGATION

MAP 1-2

BUTTE TO WHISKEY GULCH



LEGEND

- ○ SURFACE WATER SAMPLE SITE
- ● SEDIMENT SAMPLE SITE AND SURFACE WATER SAMPLE SITE
- ▲ POINT SOURCE SAMPLE SITE
- □ SEEPAGE SURFACE WATER SAMPLE SITE

0 2000' 4000

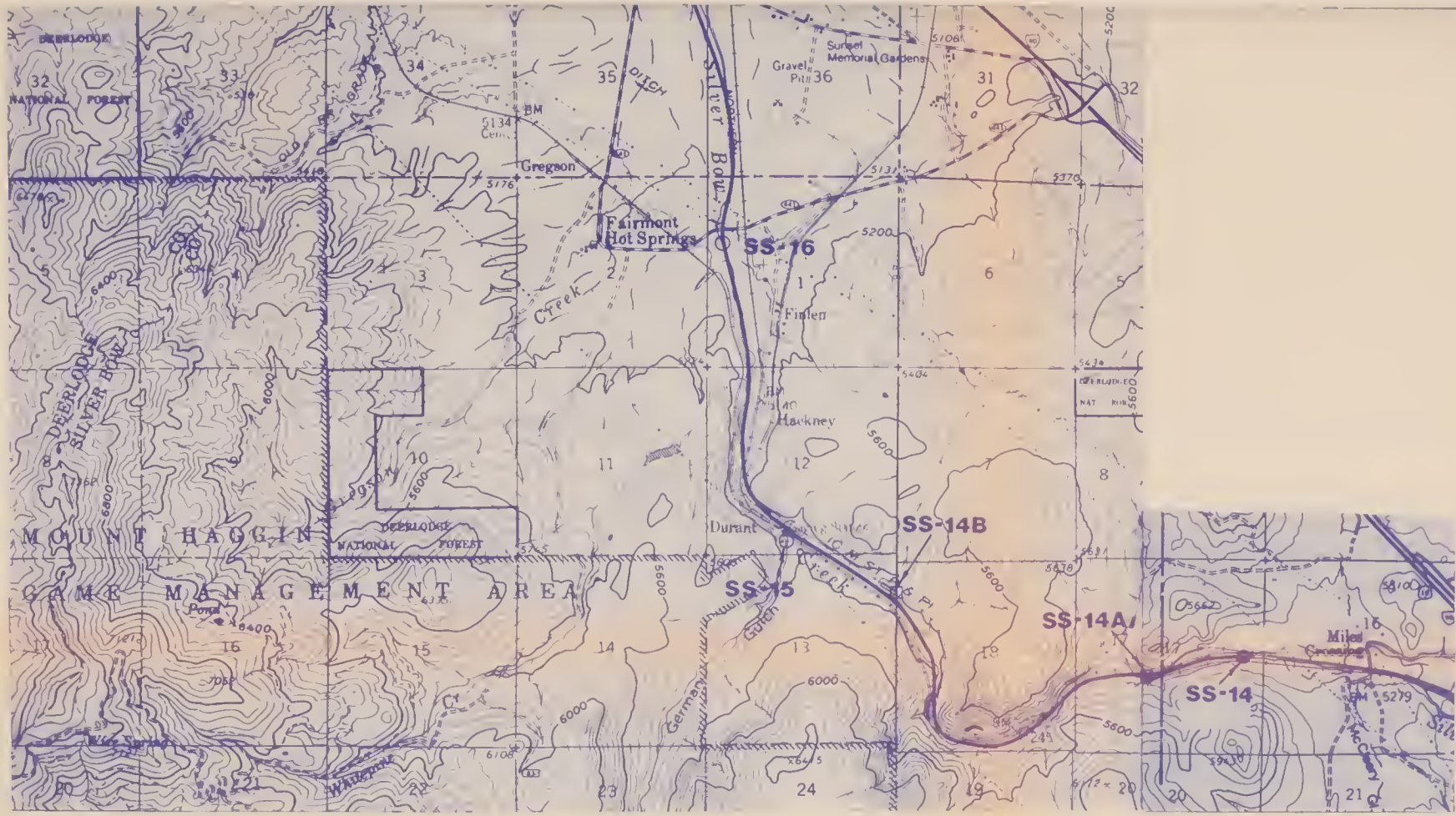
SILVER BOW CREEK

REMEDIAL INVESTIGATION

MAP 1-3

WHISKEY GULCH TO MILES CROSSING

SS-17B
SS-19
SS-17A
SS-17
SS-16C
SS-16B
SS-16A
Silver Bow Creek
Opportunity
Hensley
Stuart
Crackerville
Anaconda Country Club
Willow Glen Ranch
Gravel Pit
Rest Area
Rest Area
Mill
Ditch
Creek
Silver
Bow
Flint
Creek
Willow
Creek
Pardee
Creek
Homestead
Gulch
Spring
Creek
Yellow
Butte
Anaconda
and
Pacific
Burlington
Flanks
Divide

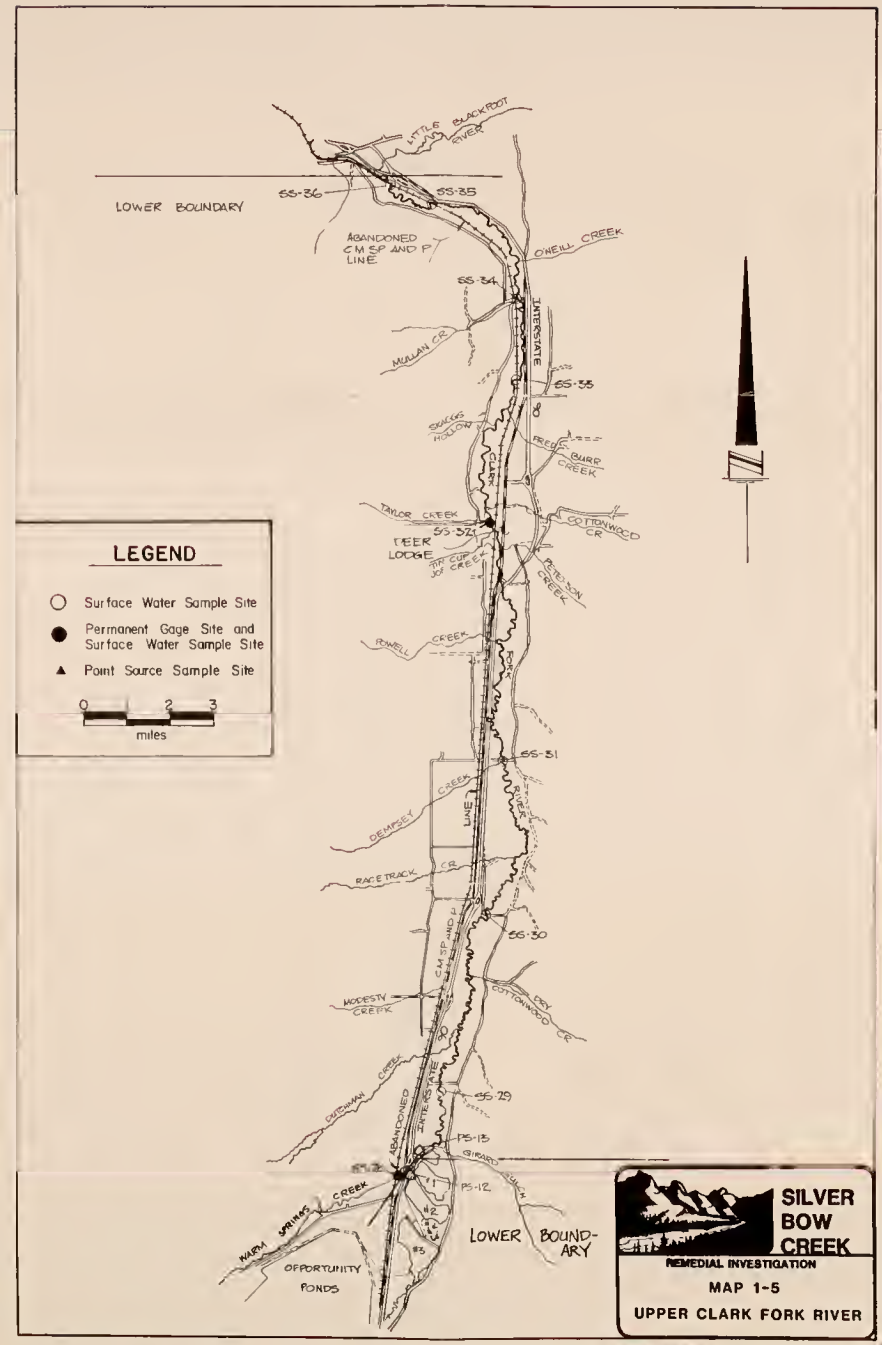


SILVER BOW CREEK

REMEDIAL INVESTIGATION

MAP 1-4

MILES CROSSING TO WARM SPRINGS PONDS


LEGEND
Surface Water Sample Site
Permanent Gage Site and Surface Water Sample Site
Point Source Sample Site
0 2 3
miles
LOWER BOUNDARY
LITTLE BLACKFOOT RIVER
SS-36
SS-35
ABANDONED C M ST P AND P LINE
O'NEILL CREEK
SS-34
INTERSTATE 90
MULAN CR.
SS-33
SQUAW HOLLOW
FRENCH GURR CREEK
TAYLOR CREEK
SS-32
COTTONWOOD CR
DEER LODGE
FIVE CUP JOE CREEK
PETERSON CREEK
POWELL CREEK
SS-31
DEMPSEY CREEK
RACETRACK CR.
SS-30
MODESTY CREEK
COTTONWOOD CR
CHERRYVALE CREEK
SS-29
ABANDONED INTERSTATE
PS-13
GIRARD
PS-12
CREEK
WARM SPRINGS
OPPORTUNITY PONDS
LOWER BOUNDARY
SILVER BOW CREEK
REMEDIAL INVESTIGATION
MAP 1-5
UPPER CLARK FORK RIVER